Visualisation of semantic relations between nodes in hypertext-based learning systems

Thesis

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Visualisation of Semantic Relations between Nodes in Hypertext-Based Learning Systems

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Abstract

The research described in this thesis is concerned with the design of hypertext-based learning systems. More specifically, it is concerned with investigating the effects of visualising semantic relations between nodes on learning in hypertext-based learning systems.

One of the most commonly cited problems with hypertext is the distraction that stems from the high level of learner control in hypertext systems. This might partly be responsible for the fact that there are few evaluations of hypertext in education which have shown the strength of hypertext over other media in terms of learning outcomes. In order to ease the problem of distraction so as to improve the application of hypertext in education, an approach employing visible link-types is proposed. It is hypothesised that labelling links explicitly with semantic relations between nodes can lower the learner's cognitive overheads in making navigational decisions so as to improve learning. It is also hypothesised that this kind of labelling can make the conceptual model of the knowledge domain intuitively clearer to the learner and thus facilitate learning.

A set of three empirical studies has been conducted to evaluate the effectiveness of the proposed approach in different situations, using different methodologies. The results found from these studies demonstrate that visualisation of semantic relations between nodes has potential for improving the use of hypertext for learning.

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Chapter 1 Introduction

This thesis is concerned with the design of hypertext-based learning systems in general, and focuses upon the effect of visible link-types on learning in such systems with the intention of improving the use of hypertext for learning. The research work presented in this thesis has been presented in several relevant international conferences (Zhao, 1992, 1994; Zhao, O'Shea, & Fung, 1993). Part of this work has also been accepted for publication in an academic journal (Zhao, O'Shea, & Fung, 1994). In this first chapter, an overview of the research work will be provided.

One of the most commonly cited problems with hypertext is the distraction that stems from the high level of learner control in hypertext systems (Marchionini, 1988). Research (Jones, 1987; Conklin, 1987; Marchionini, 1988) has shown that without sufficient guidance, learners, particularly novice learners, facing a number of alternative choices about which links to follow and which to leave alone, experience a definite distraction. This might partly account for the fact that few evaluations of hypertext in education have shown the strength of hypertext over other media in terms of overall learning outcomes (Jonassen & Grabinger, 1990). Researchers in this area have been making efforts to mitigate the problems arising from the high degree of learner control in hypertext environments. A popular approach is to consider hypertext as a framework for learning environments, needing to be supplemented by more directed guidance and access mechanisms (Hammond & Allinson, 1989; Hammond, 1993). Such guidance and access mechanisms would include graphical browsers, backtracking, guided tours, searches, queries, link filtering, etc.

Hypertext researchers and designers have noted the similarity of hypertext to semantic networks (Fiderio, 1988; Conklin, 1987; Jonassen, 1990; Tsai, 1988). Many believe that the characteristics of nodes and links offer hypertext the ability to mimic semantic networks so that hypertext can be built as knowledge representations that convey more than just information (Jonassen, 1990, 1991; Jonassen & Wang, 1993; Nelson & Palumbo, 1992). A semantic network is composed of nodes and links which represent, respectively, concepts and relations between concepts. The links in a semantic network are necessarily labelled explicitly to indicate such relations. A network without such labelling is a network, but not a semantic network (Carlson, 1991). Having taken inspiration from this, we put forward our own approach to easing the problems related to the great level of learner control in hypertext, that is, visualising link-types. It is hypothesised that labelling links explicitly with semantic relations between nodes can make it easier for the learner to navigate so as to improve learning. It is also hypothesised that this kind of labelling can make the conceptual model of the knowledge domain intuitively clearer to the learner and thus facilitate learning.

The validity of the approach needs to be tested empirically and this forms the major part of the work. When designing the empirical studies, we have considered the following two main aspects. Firstly, since we intend to investigate not only the effect of the proposed approach on the learner's gains but also the quality of the learner's interaction with hypertext, the evaluations of the proposed approach have addressed learning outcomes, learning processes, and the learner's satisfaction. A multi-faceted method has been employed in our empirical studies to accomplish such evaluations, which is largely based upon a framework suggested by Marchionini (1990). Secondly, human learning is situated in the sense that the way people learn, and the cognitive abilities they use, depend on the nature of the learning situation (Hutchings, Hall, et al., 1992). This situation includes such factors as learning tasks, subject matters, formats of learning materials, tools that support learning, and so on. Therefore, we have examined the effects of our proposed approach on both exploratory learning and goal-oriented learning and in two different kinds of hypertext systems: embedded semantic net hypertext and explicit semantic net hypertext.

The results from a set of three empirical studies with different learning situations have demonstrated that our proposed approach has positive influences on learning. More specifically, compared with those viewing no link-types, subjects viewing link-types gained more in terms of learning outcomes, performed better in the sense of the navigational quality, and felt more satisfied with the use of the hypertext systems. In addition, we have also derived a number of interesting findings from the studies, which are not the main stream of our studies but help us understand better the effectiveness of visible link-types in hypertext. They can be summarised in the following six points.

- The learner's prior knowledge might have a larger effect on learning outcomes than visible link-types.
- The learner with lower prior knowledge might benefit more from visible link-types than the learner with higher prior knowledge. The learner with lower spatial ability might take more advantage of visible link-types.
- Visible link-types might be more beneficial for structural knowledge acquisition than nodal information gain.
- A variety of factors affect users in applying their strategies for navigation.
- Learning tasks have an interacting influence with visible link-types on both learning outcomes and learning processes.

Although the findings from the current research are of interest in their own right, further studies are needed to enhance them. Two levels of enhancement are suggested in the final chapter, which include work to elaborate the results and work to extend the current research.

The rest of this chapter outlines the structure of the thesis. It consists of seven chapters, together with seven appendices.

Chapter 2 serves as a review of the literature and shows where our research fits in the area of hypertext and learning. It starts with a descriptive definition of hypertext, then the potential of hypertext for learning is explored. Following this we look into some typical educational applications of hypertext, the problem which our research is concerned with, and attempts to tackle the problem. Finally, an approach to easing the problem is proposed.

Chapter 3 provides a conceptual framework for the research reported in the thesis. It begins by introducing the concept of semantic networks. Hypertext and semantic networks are then compared in terms of knowledge representations. On the basis of the comparison, an approach is put forward for visualising semantic relations between nodes in hypertext learning systems. The approach is elaborated by examining what semantic relations are, how they are expressed and displayed in the proposed approach, and what limitations hypertext has as a knowledge representation.

In Chapter 4, the methodology of evaluating hypertext-based learning is given. In order to test the hypothesis described in Chapter 3, a multi-faceted evaluation approach is adopted to assess hypertext-based learning from angles of learning outcomes, learning processes, and the learner satisfaction level.

Chapter 5 describes the development of the experimental hypertext systems used in the studies. It includes reasons for the selection of learning materials and authoring tools, the design of information models and user interfaces, and some implementation techniques.

The contents of Chapter 6 form the main part of the present research work. A set of three empirical studies designed to test our hypothesis as put forward in Chapter 3 are described in detail. We report the methodologies adopted, present the results obtained, and discuss their implications.

The thesis concludes, in Chapter 7, by summarising the main achievements of the current research, providing a critical evaluation of the work, and proposing further work to elaborate and extend the findings from the current studies.

Chapter 2 Hypertext and Learning

2.1 Introduction

This chapter serves as a review of the literature and shows where this research fits in the area of hypertext and learning. It starts with a descriptive definition of hypertext, then the potential of hypertext for learning is explored. Following this, we look into some typical educational applications of hypertext, the problem which this research is concerned with, and attempts to tackle the problem. Finally, an approach to easing the problem is proposed.

2.2 What is Hypertext?

Hypertext is non-linear text. This should be interpreted from two perspectives: writing and reading. The author of hypertext is allowed and encouraged to create documents in a non-linear fashion, using nodes to express concepts and linking nodes together based upon the association the author believes exists between the concepts the nodes represent. As a result, the text produced in such a way can be a node-link network "which cannot be printed conveniently on a conventional page" (Nelson, 1967). Readers of hypertext are free from the linear, highly directed flow of traditional printed text. They are invited to explore a hyperdocument in their own individual pathway according to their own preferred style of reading or information needs (Jonassen, 1986). It is clear that hypertext authors must pay more attention to small details and overall structure than is required when authoring a conventional printed document and that hypertext readers must assume a much more active role than readers of normal text. Hypertext is electronic text. It is distinct from the conceptually inter-linked paper document because its links are "machine-supported" (Conklin, 1987). When readers select a hypertext link, they are transported from one node to the other automatically and immediately by the computer.

The basic building blocks of hypertext are nodes and links. The node is ideally a small portion of the document which covers one concept (Littleford, 1991). A link connects any two nodes which the author considers to be associated in some way (McKnight, Dillon, & Richardson, 1991). The linking is not arbitrary, but rather is based on the semantic relationships between nodes (Duffy & Knuth, 1990). There are two important types of links. One is referential links which usually connect a single point in a node as *reference* and a node as *referent.* The other is associative links which connect two full nodes because of certain relationship between the two concepts represented by the nodes. Links are normally directed, although most systems support *backward* movement along the link. The figure below illustrates a typical hypertext structure.

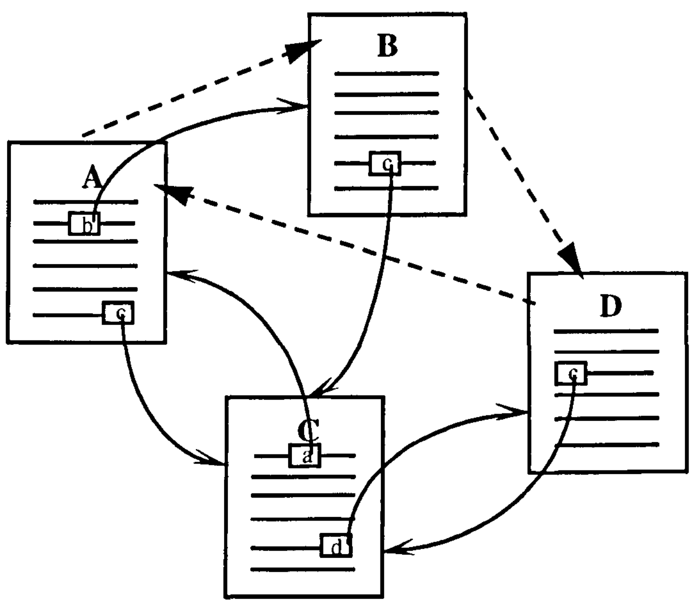

Figure 2.1 A simplified view of a hypertext structure with four nodes and nine links, where solid arrow lines represent referential links while dash arrow lines represent associative links.

Hypertext has a consistent user interface for interacting with the system: windows on the screen correspond to nodes on a one-to-one basis; windows can contain any number of link icons which represent pointers to other nodes; clicking on a link icon with the mouse causes the system to find the related other node and to immediately open a new window for it on the screen (Conklin, 1987). In addition to the basic characteristics described above, a more sophisticated hypertext system also includes additional facilities, for example, to aid user navigation (map, overview, backtracking, history trail, bookmark, etc.), or to support information search (word search, query, index, etc.). Some hypertext systems allow users to generate new nodes as well as to establish links between that new information and nodes that already exist.

Nodes of hypertext can be made of not only text but also various other media such as graphics, digitised speech, audio recordings, pictures, animation, and film clips. People use the term *hypermedia* for such hypertext systems to stress their multimedia aspects. However, the traditional term *hypertext* is used in this thesis to mean both hypertext and hypermedia.

2.3 Potential of Hypertext for Learning

It has been nearly half a century since Vannevar Bush put forward the idea of hypertext (Bush, 1945) although the term *hypertext* was only coined when Nelson developed his Xanadu (Nelson, 1967). However, only recently has interest in hypertext been sparked in the educational community with advances of hardware, software, and human-computer interface technology (Wilson & Jonassen, 1989). Although hypertext was initially invented as a new technology of structuring information rather than learning, the potential for applying such technology to learning is immediately apparent (Marchionini, 1988).

What has been widely believed about the role hypertext can play in learning is that it can provide the basis for a learning environment which possesses attractive features in information access, learner control, and collaborative learning (McKnight et al., 1991; Marchionini, 1988, 1990; Hammond & Allinson, 1989; Duffy & Knuth, 1990). First of all, hypertext can integrate varied formats and voluminous amounts of information. A considerable amount of material in a variety of formats can be instantly accessed by learners, providing them with both breadth and depth for their information needs. Secondly, hypertext is an enabling rather than a directive system, offering high levels of learner control. Learners are able to decide the pace and sequencing of navigation and to construct their own knowledge by browsing hyperdocuments according to the associations in their own cognitive structures. The learner in such an environment is forced to make decisions and evaluate new progress constantly. Therefore, hypertext offers possibilities for learners to learn not only what they want to learn but also how to learn. Finally, a sophisticated hypertext should allow users to annotate, even add to and change, hyperdocuments. Learners in such an environment can create their own paths through the hyperdocument, save and annotate them as interpretations of the content, and share these traversals and notes with teachers and fellow students. As shared paths are added to the hyperdocument, author/reader and instructor/learner relationships begin to blur, opening new possibilities for teacher-learner collaboration and interaction.

There are some other presumptions about the role of hypertext in learning. One of them suggests that we can use hypertext to represent the knowledge structure of the expert. As learners explore the knowledge domain they will learn the expert's structure. More specifically, as hypothesised by Jonassen in many of his writings (Jonassen, 1988, 1989, 1990, 1991; Jonassen & Grabiger, 1990; Jonassen & Wang, 1993), owing to its link-node feature hypertext has the ability to simulate semantic networks, and hypertext that reflects an expert's semantic structure can be used to map that structure more effectively onto the learner's knowledge structure. It is not difficult to see that Jonassen's assumption is based upon two premises. The first is the possibility for hypertext to mimic semantic networks. The second premise of Jonassen's assumption is related to the statement by Norman (1976) about learning and the experiments by Shavelson (1974) and Thro (1978). According to Norman, learning is a reorganisation of knowledge structures by constructing new nodes and interrelating them with existing nodes and with each other. During the process of learning the learner's knowledge structure begins to resemble the instructor's. The findings from the studies by Shavelson and Thro indicate that as a result of instruction, learners' knowledge structure more closely resemble the instructor's knowledge structure. However, Jonassen does not provide a systematic way of how to simulate semantic networks using hypertext, nor should we accept Norman's learning theory uncritically. Therefore, the real benefits of his assumption for learning remain to be examined. This issue will be taken up later on in this chapter.

2.4 Some Educational Applications of Hypertext

Although effective applications of hypertext in education have not yet been adequately documented, the interest in developing practical educational hypertext or more generally hypermedia systems has been growing rapidly. The current practical efforts in applying hypertext to education primarily include three aspects. The first is developing hypertext authoring systems like Intermedia (Yankelovich, Haan, Meyrowitz, & Drucker, 1988) and IDE (Jordan, Russell, Jensen, & Rogers, 1989), which have features well suited to educational purposes. The second is using hypertext systems for the delivery of educational media. The *Perseus* project (Crane, 1987, 1988, 1991) described in this section belongs to this category. The last is integrating hypertext technique with the conventional computer-assisted instruction technology. Several integrated systems of such a kind are discussed in (Bruillard & Weidenfeld, 1990; Nielsen, 1990c). Below, we overview three applications of hypertext to education, paying attention to both the virtue of each system and their evaluations.

Intermedia

Intermedia is a hypertext authoring environment rather than an end product. It was originally designed for educational uses, ~~both~~ as a tool for instructors to organise and present their lesson materials via computers and as an interactive medium for students to study the materials and add their own annotations and reports. It possesses some features which are well suited to the educational objectives. For example, it supports multiple users so that instructors and students can communicate and collaborate with one another within the context of a body of scholarly material. The Intermedia model assumes that several users (i.e. students) will access the same set of hypertext documents (i.e. course readings) and make their own annotations and new links. Intermedia stores separate files with links for each user in the form of so-called webs.

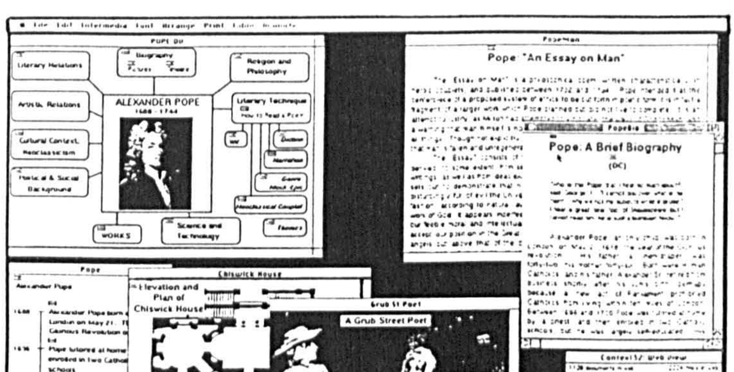

Figure 2.2 A typical Intermedia screen. The Overview diagram (upper left) together with the Web View (bottom right) shows the document structure graphically.

In addition, it has other interesting properties. For example, it provides an object-oriented framework for programmers to develop consistent applications. It allows users to create multiple bi-directional links from a specific location in one document to a specific location in another document rather than to an entire document. It facilitates effective browsing by providing two kinds of overview diagram: the web view, and the overview document. The web view provides users with an individual map of where they can go next, and is constructed automatically by the system. The overview document is constructed manually by the author using a drawing package, providing an entry point for readers wishing to find more information related to the current topic. The overview takes the form of a simple conventional layout in which the name of the current topic is in the centre and the related concepts are in a circle around it. A typical Intermedia screen is illustrated in the Figure 2.2.

IDE (The Instructional Design Environment)

IDE is a hypertext-based multimedia environment built on NoteCards (Halasz, Moran, & Trigg, 1987; Halasz, 1988), which attempts to facilitate the task of building representations in the instructional design process, from conception of instructional ideas and objectives to delivery of actual instruction. Towards this goal, IDE features three *structure accelerators* (Template cards, Autolinks and Structure Library, and Modes) that greatly reduce the overhead costs incurred in creating groups of nodes and links. Template cards allow users to define in advance new text-based card types by editing a *master template* card for each type. Each card is then created as a new instance of a template card type with the properties and text of the master template. Template cards are expected to be particularly useful for instructional designers since their task involves recording textual information with a standard format. Template cards are designed to accelerate the creation of networks by allowing the user to specify in advance text common across cards, removing the need for redundant retyping and reformatting. Autolinks allow users to specify in advance the type of the link, and the type of the destination, eliminating the need to specify these parameters at link creation time. The Structure Library allows users to explicitly define structures by creating a *master structure type* from an existing structure instance composed of interconnected cards and links. Autolinks, the Structure Library, and Template cards together direct the rapid development of semantic networks according to predefined yet tailorable specifications. The purpose of Modes is to help the user to concentrate on developing specific portions of a network by allowing users to tailor menus that interface to card, link and structure types. Only those types relevant to the current stage of the instructional design process are made salient. IDE has been used for instructional design in a number of domains, including statistics, copier repair and foreign language instruction. Its tailorability and flexibility are claimed to be features giving it superiority over other hypertext authoring systems.

Perseus

Perseus, developed at Harvard University, provides a hypermedia environment for the study of ancient Greek literature and culture. The *Perseus* hypermedia database contains, in a CD-ROM, a great amount of original Greek sources, scholarly writings that interpret the original sources, and geographic information like maps. These materials can be in different formats such as text, drawings, motion video, and still images. The user is allowed to explore the materials through automatic links that are set up by the author beforehand to connect the related information together. To illustrate its use we will take the example of a student who decides to investigate Greek tragedy. S/he is most likely to start with an essay on the development and performance of Greek tragedy, which is the part of an introduction to many aspects of Greek history and culture. This essay is linked to many original sources to provide a variety of approaches to Greek tragedy. If the student is interested in the actual theatre on the southern slope of the Acropolis where tragedy was performed in Athens, hypertext links allow her/him to view a site plan of Athens, which provides detailed views of the theatre in Athens. Furthermore, the student can investigate a series of architectural plans showing the theatre at different periods in its history by activating a button labelled *Period* located in the current card. In addition, the *Perseus* system provides users with a number of tools for their study of the materials. Translation tools such as automatic morphology analysis and dictionary lookup are designed to help students read the original Greek sources while the path-maker facility is intended to allow students to compose electronic essays within the *Perseus* environment by making a *Perseus path*. Figure 2.3 shows a screen of Perseus, and the enlarged details of the vase in the diagram or its colour photographs can be found in a separate monitor.

The system is believed by its developers to have the potential to change completely the way students approach the learning of classical Greek culture. When a textbook may have as many as a dozen source references on every page, there is little chance that the student will actually go to a traditional library or museum to check them. In a hypertext system like *Perseus*, however, the sources are a single click away, and while students still may not pursue all citations, they will no longer have to accept the author's statements uncritically. Some readers will be able to challenge the author's opinions by looking at the underlying evidence themselves.

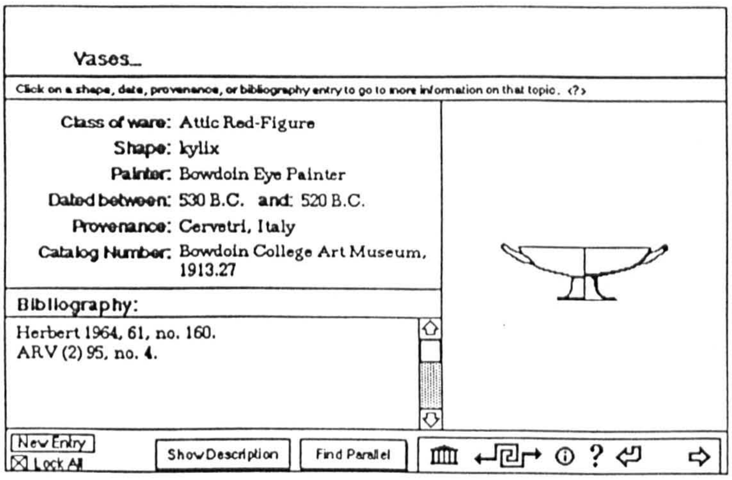

Figure 2.3 A screen from the *Perseus* system.

The developers of *Perseus* want to see what would happen to the study of antiquity if they could make not only more information, but more kinds of information, more readily accessible, and they predict a greater change of the way of learning classical

Greek culture due to the introduction of hypertext like *Perseus* into the area. However, no evaluations have been reported of the effects of *Perseus* on the learning of classical Greek culture.

Although the developers of IDE have investigated the effectiveness of IDE for instructional design in a number of domains, no work on evaluating any resultant instructional systems have been seen in the literature so far. By contrast, to assess the power and utility of Intermedia, IRIS (Institute for Research in Information and Scholarship) of Brown University has conducted a series of experiments that introduced Intermedia into existing courses and work settings (Beeman et al., 1987). Two courses, one on cell biology and one on English literature, have been taught using Intermedia. At first sight, the effects of introducing hypertext seem to have been positive. A positive correlation ($r=.29$ at *0.05* of confidence) between high Intermedia use and high grades was obtained on the English course. However, an unexpected finding led the evaluators to question the result. The story is that because the hypertext systems were not ready in time, the professor in charge of the course had to teach the course without using the hypertext system, but having already prepared the course material in the hypertext fashion. The result of this was that he changed the way he taught the course and subsequently felt that students grasped pluralistic reasoning styles better than in previous years. The students were also more satisfied with the course than in previous years. This suggests that students' improvements in grades may not have been attributable to the introduction of hypertext but rather the need to rethink the course design.

In fact, there are few evaluations so far that have demonstrated any appreciable advantage for hypertext over other media (McKnight et al., 1991). Two more examples are given below, which compare learning with hypertext to learning with print/CAI courseware respectively and give no credit to hypertext. One example is the experiment conducted by Verreck and Lkoundi (1990) with a hypertext program in an existing distance education course. They observed two groups of students, one studying the course in the hypertext form, the other studying the equivalent course in printed form. The final learning effects were equivalent for both conditions. Lanza and Roselli's empirical study is another example (Lanza & Roselli, 1991). This study examined the effects of two different approaches to teaching a programming language: the structured approach and the hypertextual approach. Two homogeneous groups of students were involved. One group was exposed to a structured form of instruction, implemented in a CAI system, while the other group used an instructional program on the same topics, developed by means of hypertextual tools. The results also indicate that the two groups had no significant differences on a performance measure.

2.5 Research Problems

The potential of hypertext for education is based on the great level of learner control supported in hypertext (Jonassen & Grabinger, 1990). Hypertext is controllable by the user, and this is the basis of the medium's real potential strength for learning (Laurillard, 1993). Learner control is an instructional strategy that permits the learner to direct the sequence of instruction, that is, to make decisions about the type and amount of instructional support that she/he thinks is necessary. Rather than the instruction directing the learner, the learner is allowed to adapt the instruction to personal preferences or abilities. While the research regarding the most appropriate quantity and quality of learner control over the conventional educational materials is mixed, the general attitude towards learner control is positive, which is based on the beliefs that learners know what is best for them and that if learners are in control of instruction, they will invest more mental effort in their learning. However, the current concept of learner control may need re-examining in the context of hypertext. This is because hypertext uses smaller information units and contain numerous branches and also because hypertext provides the vast quantities of information with a variety of formats which can be accessed extraordinarily easily (a mouse click). Obviously, the degree of learner control with hypertext can be greater than print courseware or conventional CAI (Tsai, 1988-89). The minus side of learner control with hypertext may increase to such an extent that learner control will become a factor with more disadvantages than advantages for the learner. The high level of learner control is undoubtedly responsible for one of the most commonly cited problems with hypertext: distraction (Marchionini, 1988). Research (Jones, 1987; Conklin, 1987; Marchionini, 1988) has shown that without sufficient guidance, learners, particularly novice learners, facing a number of alternative choices about which links to follow and which to leave alone, experience a definite distraction. A related problem is that of uncertain commitment, where the learner is unsure where a link will lead or what type or amount of information will be shown. As a result, flagging commitment, and unmotivated rambling may happen (Hammond, 1989, 1993). The high level of learner control may also result in missing relevant or important information, or forming wrong interpretations from the information (Marchionini, 1988). Since the use of hypertext is dependent on learner control, its potential value for learning becomes questionable (Jonassen & Grabinger, 1990).

So, does hypertext have a more important role to play in learning than other media? While we agree with the opinion that expectations of the contribution of hypertext to learning should not be unrealistically high (Clark & Salomon, 1986) and that hypertext cannot replace textbooks (Laurillard, 1993) our answer to this question is still positive because of the greater potential of hypertext in learning, although this potential has yet to be fully achieved. We believe that it is possible to control and counter the negative effects of total learner control. The question which naturally follows is how to get learner control to work best in the hypertext environment.

2.6 Efforts to Tackle the Problem

Hammond and Allinson (Hammond & Allinson, 1989; Hammond, 1993) look at hypertext as a framework for constructing an exploratory learning environment. They suggest that basic hypertext is not sufficient by itself to assure effective learning, but needs to be supplemented by more directed guidance and access mechanisms. A range of tools and techniques can be co-ordinated and deployed in such an environment in order to facilitate learning rather than merely information retrieving. We can see a variety of such facilities being proposed or adopted in the literature and in practice, e.g., graphical browser, backtracking, guided tour, search, query, link filtering, etc.

A graphical browser is a schematic representation of hypertext structures attempting to providing users with a map of what information is located where (Dillon, McKnight, & Richardson, 1990). Since the information space will normally be too large for every node and link to be shown on a single map, currently, three technological solutions are available to tackle the problem: several overview diagrams to show various levels of detail (Nielsen, 1990b); a zoom facility to allow users to see more or less detail; and a fisheye view (Furnas, 1986) to show the entire information space on a single overview diagram but in varying levels of detail. There have also been a few attempts to design three dimensional overview diagrams (Fairchild, Poltrock, & Furnas, 1988) because the structure of an information space can be three-dimensional.

There are two levels of backtracking. The simple backtrack allows the user to take one step back at a time along his current navigational track. The general backtrack displays a list of nodes previously visited and allow users direct access to any of them. Research shows that users, especially novice users, rely on backtrack to save them when they are in any situation which they can not handle (Nielsen, 1990b).

A guided tour can be thought of as a "superlink" that connects a string of nodes instead of just two nodes (Trigg, 1988; Nielsen, 1990c). As long as users stay on the guided tour, they can just issue a *next node* command to see more relevant information. The user can leave the tour at any time and rejoin the tour at her/his point of departure if he wants to later. There can be several different guided tours for various special-interest users and tours can also incorporate other tours. The guided tour may be particularly helpful for low-aptitude learners, who may not know what they need, and particularly suitable for some kinds of learning, rule learning for instance, where the constraint of forcing learners to learn prerequisite materials before superordinate materials is necessary. A real guided tour facility can be seen in Perseus (Crane, 1987) (see Section 2.4) or Hitch-hiker's Guide (Allinson & Hammond, 1989). The latter is a hypertext-based learning support environment developed at York University.

Search is used to find the occurrences of words specified by the user. The simplest search is just taking the user to the first occurrence of the search term. A more sophisticated search facility may display a window first where shown are the names of all nodes containing the search words as well as the number of the search terms that can be found in the node. Similar to the query technique used in database systems, the function of query in hypertext is to locate the node or nodes which the user is seeking. This can be done by using boolean operations to apply some combination of keyword search, full string search, and logical predicates on other attributes (such as author, time of creation, type, etc.) of nodes or links (Conklin, 1987).

Link filtering would eliminate some of the available links from the display and keep only those links of the types with which the user is presently interested. The function of link filtering is indispensable to a hypertext system where the number of links is large. This is because a large number of links makes it difficult not only for the user to choose links to follow but also for the system to show links especially in the case of graphical browsers where a map of all the links can be a hopeless tangle but a map showing only links of one or a few types can be much more manageable and useful. The link properties are generally used as filtering parameters. Users can request to see certain types of links because they may have some sense of what they are looking for, e.g., a definition of an unfamiliar word; a supporting argument for a proposition; a illustration of it; or a counter-example. Users might be only interested in those links that have been explored by them or vice versa. Since users' interest and requirements may change from one situation to another, there is no single optimal strategy for filtering. A good filtering facility will thus be able to offer several different methods and allow the user to select the one that is most appropriate (Tomek & Maurer, 1992).

In order to investigate their suggestion that basic hypertext systems need to be armed with more directed guidance and access mechanisms, Hammond and Allinson (1989) carried out an experiment in which all subjects used the same material held in a hypertext form, but with differing guidance and access facilities available. The baseline group had "raw" hypertext with no additional facilities, while other groups had either a map or index or guided tours available, and a final group had all three facilities (map, index, tours) available. Half of the subjects were given a series of questions to answer while accessing the material (a directed task) while the other half were instructed to make use of the material to prepare for a subsequent multiple-choice test (an exploratory task). The results showed that the additional facilities allowed more accurate overviews of the available material and resulted in a higher rate of exposure to new rather than repeated information. However, for both tasks no significant differences occurred in task performance between groups. Hammond and

Allinson attribute this lack of difference to the fact that the materials and tasks used required little strategic organisation, and they therefore caution against extrapolating such results to situations other than simple rote learning of relatively unstructured material. In addition, the experiment also suggests that a range of access tools can be effectively used with no apparent cost in terms of interface complexity.

From a different point of view, Nelson and Palumbo (1992) believe that the current application of hypertext for learning remains in the primitive stage, i.e., solely used for knowledge presentation. Most current hypertext systems for education, according to their view, focus on the information presentation capabilities of the medium. In their opinion, simply allowing learners to quickly access a body of information, even in the learner-controlled, non-linear manner supported by the system, does not ensure learning any more than a library does. To fully achieve the potential of hypertext for instruction, current hypertext systems must be augmented by promoting hypertext from the current stage of knowledge presentation to more advanced stages of knowledge representation and knowledge construction. Hypertext as a knowledge representation system should make explicit the relationships between the information contained in the nodes. Such systems often utilise *knowledge maps* or graphical browsers to represent the organisation of the information. Hypertext as a knowledge construction system should support learners in direct interaction with information, allowing them to build nodes and links, annotate, share ideas with others, or even interact in context-rich simulations. However, Nelson and Palumbo have not reported any further work to judtify their statement, A study has been carried out by Jonasson and Wang (1993), which is very relevant to Nelson and Palumbo's statment and is described in the rest of this section. The result from the study shows that the explicit display of structural knowledge has effects on learners' knowledge acquisition under certain conditions.

As described earlier in this chapter, Jonassen (1990, 1991) holds a similar view to this. He believes that hypertext may be made to reflect the semantic structures of human memory. Further, he hypothesises that mapping the semantic network of an expert or knowledgeable person onto the structure of a hypertext and explicitly illustrating that structure in the hypertext will contribute to the development of the learners' knowledge structures while using the hypertext to learn.

To test this hypothesis, Jonassen and Wang (1993) conducted three empirical experiments. In the first experiment, they compared the extent to which users acquired structural knowledge from three levels of explicitness of structural knowledge display. One group was provided with the most explicit structural cue, i.e., a graphical browser which is, according to the researchers, the expert's semantic map. Less explicit structural cues were given to the second group. Whenever the user in this group activated a link, s/he would see the semantic nature of that link in a pop-up window before actually moving to the link destination. No structural information was supplied to the control group. An exploratory learning task was required of all subjects. The result showed no significant difference between three groups in structural knowledge acquisition. Jonassen and Wang attributed the lack of main effects in this study to a lack of generativity in the way students processed the information. They believed that merely attending to structural cues might not engender generative processing of information. Therefore, a second experiment was carried out where the structural cues were compared with a more generative process in which the students determined the nature of the link relationships for themselves, rather than being informed by the program. In this experiment, three treatments were also employed. The control treatment and pop-up window treatment were the same as in the previous experiment, but another experimental group was given pop-up windows rather than the graphical browser where 12 different link types were presented, and the students were required to classify the link type that most accurately described the nature of the relationship implied by the link that they were traversing.

The same exploratory learning task as in the previous experiment was adopted despite the generative activity required of one of the experimental groups. As with the first experiment, there was no significant difference between three groups in structural knowledge acquisition. It was found that learners were not substantively engaged in meaningful learning by the assigned learning task. Even the generative treatment did not engage the learners in generative processing because many in the generative treatment group discovered quickly that generating two errors would produce the correct answer, which enabled them to continue. Thus, Jonassen and Wang decided to undertake a third experiment where a meaningful reason was provided to attend to the structural information. In this experiment, the effects of two treatment factors were assessed. The first factor compared structural knowledge acquisition resulting from being assigned to develop a semantic network of the ideas contained in the hypertext and resulting from being assigned the same exploratory learning task as before. The second factor concerned the level of structural support provided, with the control treatment providing no structural cues and the graphical browser treatment providing explicit information. The result showed a combined effect of the above two factors on structural knowledge acquisition, that is, the group with the graphical browser and semantic networking task performed significantly better than other groups in structural knowledge acquisition ($F=2.77$, $p<.05$). In summary, the studies show that depicting knowledge structures in the form of a graphical browser or by making explicit the structural nature of the links during traversal does not improve learners' acquisition of structural knowledge but that it can be improved by getting learners to focus on structural relationships.

2.7 A Proposed Solution

The approach proposed in this thesis to easing the problem stemming from the greater level of learner control is inspired by the notion that hypertext systems have the ability to simulate semantic networks so that they can be built as knowledge representations that convey more than just information (Jonassen, 1990, 1991; Jonassen & Wang, 1993; Nelson & Palumbo, 1992). The approach is mainly concerned with the question of how to create hypertext as a knowledge representation. A semantic network is composed of nodes and links which represent, respectively, concepts and relations between concepts, and the links in a semantic network are necessarily labelled explicitly to indicate such relations (Rumelhart & Norman, 1985). A network without such labelling is a network, but not a semantic network (Carlson, 1991). Visualisation of semantic relations between nodes in hypertext is assumed to be beneficial in both guiding learner navigation and in conveying knowledge from the author to the learner. It seems intuitive that letting users view what relationships there are between nodes would be more helpful for them to make decisions about which links to follow than letting them only know whether there are relationships between nodes. Simply stating that a node *whale* is associated with a node *mammal*, for instance, does not convey as much information as stating that *whale* is an example of *mammal*. More detailed description of the proposed solution will be given in the next chapter, Hypertext and Semantic Networks.

In fact, some researchers and designers of hypertext have already noted the importance of making the relationships between nodes visible to users. Parunak (1991) suggests that "if each link is labelled to indicate the kind of relation that it specifies, the information in the graph [the hypertext structure diagram] becomes much clearer and human users can more easily select from a variety of links that begin at a single node, based on the kind of further information they want." When Collier (1987) describes his hypertext system called Thoth-II, he points out that explicitly representing the conceptual relations that hold among concepts can serve as a guide to a user as the reason for the connections among pieces of the structure are made at least slightly more specific. Jonassen and Grabinger (1990) also state that "the information model describes the organisation of ideas and their interrelationships which, if explicitly signalled, may help the user comprehend better the information or problem that is embedded in the system." In practice, links are typed and relationships between nodes are made explicit in some hypertext systems such as TextNet (Trigg, 1983), Thoth-II (Collier, 1987), SemNet (Fairchild, Poltrock, & Furnas, 1988) and NoteCards (Halasz, Moran, & Trigg, 1987; Halasz, 1988). Figure 2.4 shows an example of Thoth-II's DG browser, where the dots represent nodes; the thin lines represent links; and each node and link is directly labelled. By contrast, links in the browser of NoteCards are labelled indirectly with different dashing styles distinguishing different types of links and with being placed beside the browser window the legend including each dashing style followed by the name of the link type it represents, as illustrated in Figure 2.5.

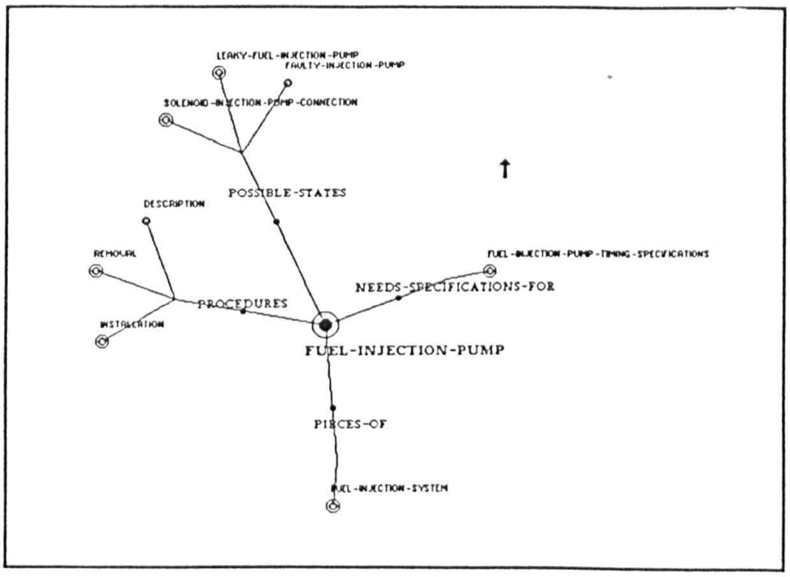

Figure 2.4 A DG browser in Thoth-II.

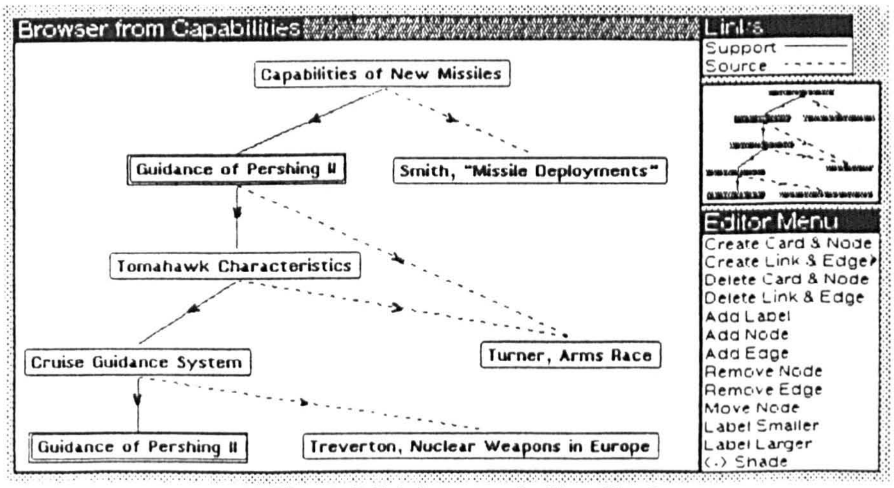

Figure 2.5 A browser in NoteCards.

However, very little research done so far has been concerned with how effective visualisation of relationships between nodes in hypertext is. As a result, it has not been clear what roles visible link-types play in the various uses to which hypertext has been put in general and in learning with hypertext in particular. The focus of the research presented in this thesis is upon the development and implementation of a series of experiments designed to test the beneficial effects of visible link-types upon learning with hypertext. Although this research has some aspects in common with Jonassen and Wang's work (Jonassen & Wang, 1993) in that both are concerned with how explicitly illustrating the semantic structure in hypertext influences learning with hypertext, they differ from each other in following significant respects. Jonassen and Wang place their focus on the structural cue, providing the learner with either a graphical browser or an unstructured list of nodes with or without a pop-up window which shows the semantic nature of each link, whereas our concentration is upon the relationship between nodes, attaching the semantic relation for each link or not. Only learners' structural knowledge gains are assessed in the work by Jonassen and Wang, while both learning outcomes and learning processes are evaluated in our studies.

2.8 Summary

Having examined both the potential of hypertext for learning and the problem of learning with hypertext, we suggest that hypertext does have an important role to play within education and learning, and that visualisation of relations between nodes is one possible approache to easing the problem stemming from the greater level of learner control in hypertext systems so as to improve the use of hypertext for learning. However, the effectiveness of this approach needs to be tested empirically, which is the main task of the research presented in this thesis.

Chapter 3 Hypertext and Semantic Networks

3.1 Introduction

In the previous chapter, hypertext and learning were discussed. This chapter provides a conceptual framework for the research reported in the thesis. It begins by introducing the concept of semantic networks. Hypertext and semantic networks are then compared as knowledge representations. On the basis of the comparison, an approach is put forward of visualising semantic relations between nodes in hypertext learning systems. The approach is elaborated by examining what semantic relations are, how they are expressed and displayed in the proposed approach, and what limitations hypertext has as a knowledge representation.

3.2 Semantic Networks

The semantic network was first suggested by Quillian (1968) as a model of semantic memory. It is one of the earliest methods of knowledge representation used in Artificial Intelligence (AI). The network is called *semantic* because it encodes information about meaning. The basic notion, described by Rumelhart and Norman (1985), is that:

> Knowledge can be represented by a kind of directed, labelled graph structure in which the basic structural elements are a set of nodes interrelated by relations. Nodes represent concepts in memory. A relation is an association among sets of nodes. Relations are labelled and directed. (p. 24)

The semantic network is distinct from other knowledge representing methods (e.g. Predicate calculus, Schemata, Frames, Scripts, Production systems, etc.) by virtue of its graphical features, which make its meaning clear (Rada, 1991, p. 35). For example, one might be able to work out the meaning represented by the semantic network demonstrated in Figure 3.1 without any great difficulty. What this network conveys is that hypertext is created by authors, contains documents, runs on computers, and serves readers. In semantic networks, an arc connecting two nodes merely means the existence of a certain relationship between the two concepts while it is the label and the arrow on the arc which indicate the actual relationship. Both labels and arrows are essential for inferences and deductions that the human or machine must perform on a semantic network. There are a number of requirements to be met before a representation can be classed as a semantic network. Some of them will be discussed later in the following sections when hypertext and semantic networks are compared.

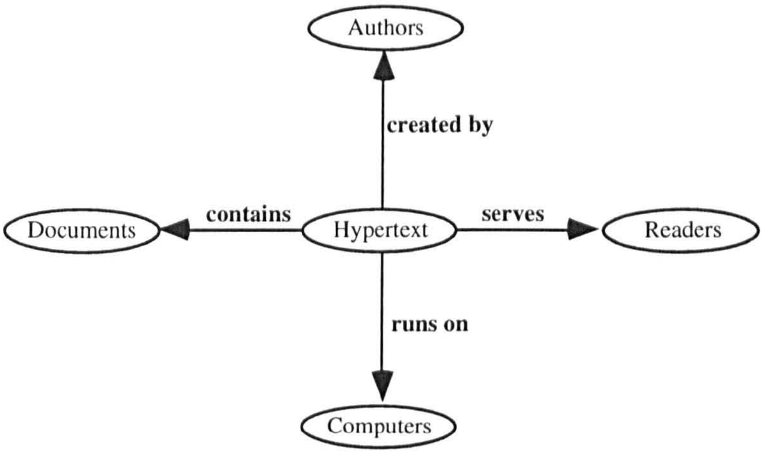

Figure 3.1 A simple semantic network.

3.3 Similarities of Hypertext and Semantic Networks

Bush's Memex ("memory extender") (Bush, 1945), which is known as the first prototype hypertext system was, as its name implies, designed to model the associative structure of human memory. Bush believed that since the human mind operates by association, our machines for storing and accessing information should also reflect those associative structures. When Nelson (1965) first coined the term *hypertext*, he regarded hypertext as a means of describing networks of knowledge. The origin of both hypertext and semantic networks is an attempt to deal with human knowledge in the context of machines. The associative links are the key element of both semantic networks and hypertext. The essential attribute of human semantic memory is not the storage or retrieval of specific units of knowledge, but rather the organisational schemes by which knowledge is associatively related. Both hypertext and semantic networks provide computerised technologies with which we can attempt to achieve similar organisational structures.

As described in the previous chapter, the basic structure of hypertext is document blocks interrelated by machine-supported links. The similarity of this structure and semantic networks is rather obvious. In his widely referenced hypertext survey article (Conklin, 1987), Conklin points out:

> The analogy (of semantic networks) to hypertext is straightforward: Hypertext nodes can be thought of as representing single concepts or ideas, internode links as representing the semantic interdependencies among these ideas, ... (p. 37)

Carlson (1991) explores this issue more deeply. She indicates that links in hypertext not only connect nodes but can also record types and attributes of relationships as do the links in semantic networks, turning documents into a web of identified relationships. Researchers in the area have noted this resemblance between hypertext structures and semantic networks, and reasoned further. Jonassen (1990, 1991, 1993) believes that the characteristics of nodes and links offer hypertext the ability to mimic semantic networks. Moreover, he assumes that hypertext reflecting an expert's semantic structures can be used to map that structure more directly or explicitly onto the learner's knowledge structures.

Based on the resemblances between hypertext and semantic networks described here a number of experimental hypertext systems are claimed to have incorporated semantic networks in their frameworks. These systems include Thoth-II (Collier, 1987), TextNet (Trigg, 1983), and SemNet (Fairchild et al., 1988).

3.4 Differences Between Hypertext and Semantic Networks

However, although they do share some similarities as described above, i.e., they are structured as node-link networks and intended to represent "knowledge" (Travers, 1989), it must be made clear that hypertext is not the same as semantic networks. The differences between them can be viewed from at least the following three aspects.

Firstly, in a semantic network, the whole knowledge base, including both the knowledge structure and the knowledge that it contains, is stored within a directed, labelled graph, where nodes are simply words (see Figure 3.1). However, for hypertext such a graph is not capable of holding the whole knowledge body but only the structure of knowledge that hypertext contains since nodes of hypertext are normally document chunks rather than just words, as demonstrated by Figure 3.2. Secondly, semantic networks aim to provide a convenient and powerful formalism for representing knowledge, by which represented knowledge can be mechanically interpreted (Rumelhart & Norman, 1985). In other words, there must be algorithms that can make use of such a formal representation to make inferences and deductions mechanically (Woods, 1975). By contrast, hypertext is a relatively informal representation of knowledge. Hypertext writers do not need to consider the machine interpretability of representation when they are creating hypertext (Conklin, 1987). It is the user rather than the machine who, by browsing hypertext, interprets the represented knowledge. Corresponding to the mechanical referencing and interpreting facilities applied to semantic networks, browsing tools are usually provided for the users of hypertext. The final aspect is the most important of the three. To become a semantic network, concepts in the network must be linked to each other by their semantic relations (more detailed descriptions of which will be given later in this chapter) rather than by some arbitrary (for example, alphabetical) ordering (Conklin, 1987). No such constraint is imposed on hypertext. Hypertext is more concerned with the existence of connections among document chunks than the nature of the connections and the rationale for their existence. Various kinds of relations and even "content-free" connections are allowed to link nodes to make documents become non-linear. From this point of view, a hypertext system is more like an information presentation system than a knowledge representation system (Nelson & Palumbo, 1992).

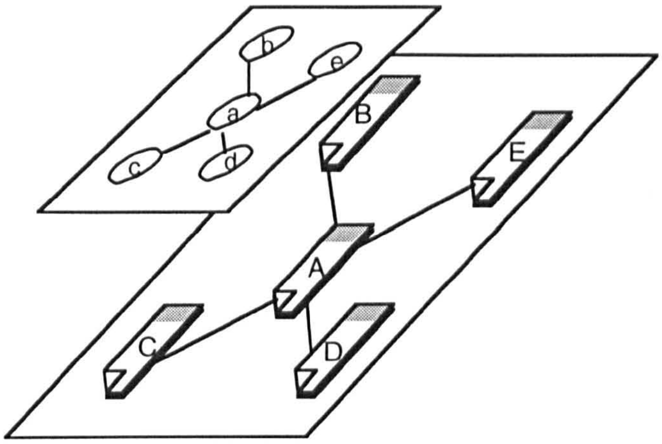

Figure 3.2 The correspondence between hypertext and its abstraction. The bottom layer represents real hypertext where each node is a document chunk while the top layer represents the abstraction of the hypertext where each node is just words.

3.5 Research Hypothesis

According to one account of current learning theories (Norman, 1976), learning involves the reorganisation of knowledge structures by constructing new knowledge nodes, then connecting them to existing knowledge nodes and with each other. The learner's knowledge structures increasingly resemble the instructor's during the process of learning. Thus, a hypertext learning system should be designed to be capable of helping the reorganisation of the learner's knowledge structures by facilitating the transfer of the hypertext author's semantic structure to the learner's

(Jonassen, 1990, 1991; Nelson & Palumbo, 1992). From the above comparison of hypertext and semantic networks, it becomes clear that although hypertext is not the same as semantic networks, the features of nodes and links provide hypertext with the ability to imitate the semantic network to a certain extent. This can be done by linking hypertext nodes by semantic relations and labelling links explicitly to display such relations. Considering the issue of designing hypertext learning systems, it is natural to hypothesise that labelling those links explicitly with semantic relations between nodes in this way might improve learning. This is because hypertext with such labelling is more like a semantic network, so that the conceptual model of the knowledge domain is intuitively clearer to the learner and that learners are able to accommodate their own knowledge structures to the hypertext author's more easily. Moreover, it is assumed that this kind of labelling can lower the learner's cognitive overheads in making decisions about which links to follow and which to leave alone. This is because such labelling can serve as a guide to the learner by providing more specific reasons for the connections among nodes in the local hyperspace, or even in the global space. Before discussing in more detail how to test this hypothesis, we need to clarify two crucial matters: the concept of semantic relations, and the meaning of hypertext notations.

3.6 Semantic Relations

Semantic relations are concerned with meaningful associations between concepts such as the relations of contiguity, similarity, and contrast used by Aristotle to explain the sequence of ideas in recall. It seems very difficult, if not impossible, to give *semantic relations* a precise definition. The approach adopted here to addressing this issue is by firstly looking at two specific classifications of semantic relations used by two research projects, then proposing a set of semantic relations mainly used in designing our experimental systems, and finally identifying some important properties of semantic relations.

3.6.1 Two Existing Classifications of Semantic Relations

Let us begin the discussion of semantic relations by looking at two practical projects, gIBIS and TextNet, where the types of semantic relations between nodes are considered, but the considerations are limited to specific application areas and demanded levels of detail. The former is constrained at the conceptual design level, while the latter is concerned with scientific writing.

The system gIBIS (graphical Issue Based Information System) (Conklin & Begeman, 1989) is specifically designed to facilitate and capture policy and design discussions. It builds upon the theory that human memory is a semantic network and that in the formulative stages of creative activity much of what is produced is a collection of associations. The system provides only nine different kinds of semantic relations. These are: *responds-to, questions, supports, objects-to, specialises, generalises, replaces, refers-to,* and *be-suggested-by*. For example, a Position *Responds-to* an Issue; an Argument *Supports* or *Objects-to* a Position; Issues may *Generalise* or *Specialise* other Issues, Positions, and Arguments. Here, Issue, Position, and Argument are the only three types of nodes allowed. The reason for this is the specific application of the system. The focus of gIBIS is on the area of design and design deliberation. The imposed simpler framework of gIBIS is claimed to be able to help users to concentrate their thinking on the hard, critical parts of the problem, and to detect incompleteness and inconsistency in their thinking more readily.

TextNet (Trigg, 1983) is described as a computer system supporting non-linear text in which documents are organised as "primitive pieces of text connected with typed links to form a network similar in many ways to a semantic net." Since the system is dedicated to scientific writing, the designer's considerations of semantic relations are limited to capturing "the essential relationships between pieces of text comprising scientific text and commentary." Links in Textnet are divided into two major categories: normal and commentary. Normal links serve to connect nodes making up a scientific work as well as to connect nodes living in other works. A work is a piece of relatively complete writing. Its goal is to communicate information and/or beliefs to the reader. A work usually includes the following functional parts: specifying context, problem posing, theory declaration, arguments, and data as evidence for a theory. Commentary links connect statements about a node to the node in question. Thirty-four different semantic relations conveyed by normal links and fifty-two conveyed by commentary links are listed in Table 3.1 and 3.2 respectively. For example, the relation of *C-source* expresses that one node is the source of the concept contained in the other node. The prefix *C-* means it belongs to the group of *citation* relations. For another example, the relation of *P-unimportant* expresses that the commentary node is to say that the problem raised in the node being commented upon is unimportant (or uninteresting) for researchers in the field.

Table 3.1 Semantic relations conveyed by normal links in Textnet (Trigg, 1983).

Citation	Generalisation/Specification	Summarisation/Detail
C-source	Abstraction/Example	Alternate-view
C-pioneer	Formalisation/Application	Rewrite
C-credit		
C-leads	Argument	Simplification/Complication
C-eponym	A-deduction	Explanation
	A-induction	
Background	A-analogy	Correction
Future	A-intuition	Update
Refutation	Solution	Continuation
Support		
Methodology		
Data		

Table 3.2 Semantic relations conveyed by commentary links in Textnet (Trigg, 1983).

Comment	*Points*	*Data*
Critical	Pt-comment	D-comment
Supportive	Pt-trivial	D-inadequate
	Pt-unimportant	D-dubious
Environment	Pt-irrelevant	D-ignored
E-comment	Pt-redherring	D-irrelevant
E-misrepresent	Pt-contradict	D-inapplicable
E-vacuum	Pt-dubious	D-misinterpreted
E-ignored	Pt-counter	
E-Isupersede	Pt-inelegant	Style
E-Irefute	Pt-simplistic	S-comment
E-Isupport	Pt-arbitrary	S-boring
E-Irepeat	Pt-unmotivated	S-unimaginative
		S-incoherent
Problem Posing	*Arguments*	S-arrogant
P-comment	A-comment	S-rambling
P-trivial	A-invalid	S-awkward
P-unimportant	A-insuff	
P-impossible	A-immaterial	
P-ill-posed	A-mislead	
P-solved	A-alternate	
P-ambitious	A-strawman	

3.6.2 A Set of Semantic Relations

In this section, we distiguish a set of semantic relations which is largely based upon the works by Parunak (1991) and Chaffin & Herrmann (1988), and used in designing our experimental systems. Semantic relations concern relationships between concepts. A concept can be the idea of a class of objects (either abstract or concrete) or a belief/fact/opinion (Howard, 1987). The former kind of concepts can be represented by a word/phrase (e.g. dog, red) so that it will be referred to as a *word-concept*. The latter kind of concepts can be represented by a proposition (e.g. "fish live in water", and "I see what you mean") so that it will be referred to as a *proposition-concept*. No matter how large such a concept is in the latter case, it is possible that the concept can be summarised, at least approximately, with a single proposition (Parunak, 1991). The semantic relations we have distinguished can be divided into two categories: two concepts associated where both are *word-concepts*, two concepts associated where both are *proposition-concepts*, which we shall call *word-word* relations and *proposition-proposition* relations respectively.

WORD-WORD RELATIONS

I. ***Contrast***

• *Contrary*	e.g. old-young, happy-sad
• *Contradictory*	e.g. alive-dead, male-female
• *Reverse*	e.g. attack-defend, buy-sell
• *Directional*	e.g. front-back, left-right
• *Incompatible*	e.g. happy-morbid, frank-hypocritical
• *Asymmetric contrary*	e.g. hot-cool, dry-moist
• *Pseudo antonym*	e.g. popular-shy, believe-deny
• *Attribute similar*	e.g. rake-fork, painting-movie

II. ***Similar***

• *Synonymity*	e.g. car-auto, buy-purchase
• *Dimensional similar*	e.g. smile-laugh, annoy-torment
• *Necessary attribute*	e.g. bachelor-unmarried, tower-high
• *Invited attribute*	e.g. food-tasty, cut-knife
• *Action subordinate*	e.g. talk-lecture, cook-fry

III. ***Class Inclusion***

• *Perceptual subordinate*	e.g. animal-horse, flower-rose
• *Functional subordinate*	e.g. furniture-chair, tool-hammer
• *State subordinate*	e.g. disease-polio, emotion-fear
• *Activity subordinate*	e.g. game-chess, crime-theft

- *Geographic subordinate* e.g. state-New Jersey, country-Russia
- *Place* e.g. Germany-Hamburg, Asia-China

IV. ***Case Relations***

- *Agent-action* e.g. artist-paint, dog-bark
- *Agent-instrument* e.g. farmer-tractor, soldier-gun
- *Agent-object* e.g. baker-bread, sculptor-clay
- *Agent-recipient* The agent is a person or a thing that evokes an action whereas the recipient is a person or a thing that receives that action. The action can be arbitrary so that a relation of this kind can be by no means specified by a word-pair. A verb is usually used to identify a specific relation of this kind. e.g. "John loves Mary", and "Rain waters the land"

V. ***Part-Whole***

- *Functional object* e.g. engine-car, tree-leaf
- *Collection* e.g. forest-tree, fleet-ship
- *Group* e.g. choir-singer, faculty-professor
- *Ingredient* e.g. table-wood, pizza-cheese
- *Functional location* e.g. kitchen-stove, house-dining room
- *Organisation* e.g. college-admissions, army-corps
- *Measure* e.g. mile-yard, hour-minute

PROPOSITION-PROPOSITION RELATIONS

I. ***Orientation***

- *Location*

  This joins a proposition to a description of the place where that proposition applies.

- *Temporal*

  This describes the chronological relationship between the states or events described in two propositions.

- *Circumstance*

  This joins a proposition to another proposition that describes aspects of its environment other than local or temporal.

II. *Implication*

- *Causation*

  This joins one proposition to another that describes its cause. e.g. “My tyre is flat” - “There is a piece of glass stuck in my tyre”

- *Purpose*

  This joins one proposition to another that describes its purpose. e.g. “I'm going on a vacation” - “I need a rest”

- *Condition*

  This joins one proposition to another whose truth insures the truth of the first. e.g. “It will be a nice day tomorrow” - “The sky is red this evening”. Condition and causation are easily confused. Condition simply records a correlation in the truth of two propositions, without considering whether one causes the other or whether both are effects of a common cause. Causation claims that one directly causes the other.

- *Concession*

  This joins a proposition to another that might be thought to invalidate the first. e.g. “I can finish my work” - “There are only two hours left”. The example can be put as “I can finish my work although there are only two hours left”.

- *Warning*

  This joins a proposition that describes an obligation to another describing an undesirable consequence that will arise if the obligation is not fulfilled. e.g. "Lubricate the thrust bearing every six months" - "Failure of the main thrust bearing can result"

- *Evidence*

  This joins a proposition to another that provides data that support it and from which it is induced. This relation is similar to the condition relation, but weaker. If one attaches a probability weight to the evidence relation, then an evidence relation with a weight of 100% becomes a condition relation.

III. ***Illustration***

- *Manner*

  This joins one proposition to another that describes the manner or style in which the event or state in the first came about.

- *Comparison*

  This joins two propositions that are different from one another but show points of similarity, and draws attention to those similarities. This type of relation is corresponding to the relation of "similar" in the "word-word" case, and can be further classified into a set of sub-types.

- *Contrast*

  This joins two propositions and draws attention to the differences between them. The relation is similar to the relation of "contrast" in the "word-word" case, and can be further classified into a set of sub-types.

IV. ***Paraphrase***

- *Amplification/Summary*

  They are inverses of one another and associate a proposition that makes a point concisely with another that gives more detail.

- *Abstraction/Instance*

  They are inverses and associate a generic proposition with a specific form of it.

- *Equivalence*

  This joins two propositions that contain the same information in different words.

3.6.3 Some Properties of Semantic Relations

We now come to the most important part of the current topic, that is a number of relevant properties that semantic relations possess. The formal definition of relations used in discrete mathematics will be borrowed to make the description easier and less ambiguous. We will first look at the general concept of relations, and then focus on semantic relations.

Given sets S and T, if we pair each individual member of S with every member of T, we obtain all the possible pairs between two sets. This is called the Cartesian product of the two sets and is labelled S×T. A relation is any subset R of S×T, i.e., any subset of ordered pairs drawn from S×T is a relation denoted as R.

For example, let S be the set of all students in a university, and let C be the set of all courses that the university offers. The relation of *enrolment* consists of all ordered pairs whose first entries are students and whose second entries are the courses the students are currently enrolled in. Sets S and T can be the same set. In this case, we will say that a subset R of S×S is a relation on S. For example, the relation of *marriage* is a relation on the set of *people*. This relation is composed of all couples who are married to each other, and both entries of each pair belong to the set of *people*. We will specify some important properties of relations as follows, focusing on those defined on one set instead of two since semantic relations can be viewed as being defined on one set which consists of all concepts.

(1) According to the definition of relations given above, a relation is a set of ordered pairs, which implies that the relation has a direction. The direction is always from the first entry to the second entry in each pair. As a result, the graphical representation of a relation should be a directed graph.

(2) Given a set S, there can be theoretically as many as $N^1 + N^2 + N^3 + \cdots + N^N = N(N^N - 1)/_{N-1}$ relations to be defined on S, where $N = |S|$ is the size of S, i.e., the number of members of S. There can be an infinite number of relations to be defined on S if S is an infinite set.

(3) Let R be a relation on a set S, R is said to be a symmetric relation if *(a, b)* in R implies that *(b, a)* is also in R. For example, let S be a set of students and let R be a relation on S such that *(a, b)* is in R if and only if *a* is in a class that *b* is in. If *a* is in a class that *b* is in, then, clearly, *b* is also in a class that *a* is in. Thus, the relation R is a symmetric relation.

(4) Consider a relation R on a set S, The converse relation of R, denoted R^{-1}, is defined by $R^{-1} = \{(b,a) | (a,b) \in R\}$. Take the relation of *father-son* as an example. Its converse relation is the relation of *son-father*. If R is symmetric, R^{-1} is necessarily symmetric.

Semantic relations are a group of relations defined on the set that consists of all concepts and ideas human beings can conceive. As discussed above, semantic relations have a direction, which is called the semantic direction. For example, if a concept pair *(a, b)* belongs to the relation *supports* then this should be read "concept *a supports* concept *b*", and thus the semantic direction is from *a* to *b*. Since the concept set is considered as being infinite, the number of kinds of semantic relations can also be thought to be infinite. However, only a small number of different types of semantic relations are normally used. Some semantic relations are symmetric, e.g. the relation of *contrast*. In most cases, a semantic relation has its converse relation and they can be used to express the same semantic content. For example, the converse relation of *generalises* is simply *specialises* and "*a generalises b*" is equivalent to "*b specialises a*."

3.7 Semantics of Hypertext Notations

Having discussed the concept of semantic relations, we now come to the issue of considering what is meant by a hypertext construct, i.e., the semantics of the hypertext notation, and how it can be consistently interpreted and generally understood. Hypertext constructed in such a way that nodes are linked according to semantic relations and that such relations are typed and explicitly displayed, is a semantic-net-like knowledge representation. However this representation is expected to be interpreted by human readers rather than machines. Therefore, the notation adopted in such a representation must be more compatible with human information encoding system than those used in semantic networks. What is devised in this section is a straightforward but function-limited notation.

Firstly, we look at the issue of relation expressions. People have the ability to express semantic relations by using common words and phrases (Chaffin & Herrmann, 1988). For example, people know that an engine is a *component* of a car and that farmers *drive* tractors. Furthermore, a semantic relation with its two arguments forms a proposition. Here are some examples. The relation of *antonym* can be expressed by the proposition frame, "A is the opposite of B". The *class inclusion* relation can be expressed in the form "A is a kind of B." The relation of *agent-recipient* is expressed by the fashion of "A <verb> B." The way of interpreting a semantic relation is to identify such a proposition, where the name of the relation plus the relation's closing argument corresponds to the predicate of the proposition, and the relation's starting argument corresponds to the subject of the proposition. Here are more example taken from our experimental hypertext systems. The relationship between *lists* and *static lists* belongs to *class inclusion* relation and it is expressed by *a type of. Arrays* and *static lists* have an *agent-recipient* relation which is expressed by the verb *represent.*

The next issue is how to display semantic relations in hypertext. We will deal with this in two different situations. According to Halasz (1988), the current generation of hypertext can be divided into two categories in terms of whether or not a graphical overview of the network structure is used for navigation. Systems such as HyperTies (Shneiderman, 1987) and Guide (Brown, 1987) where no structure diagrams are equipped, fall into the first category, called embedded semantic net hypertext systems. Systems like NoteCards (Halasz, 1988) and Intermedia (Garrett, Smith, & Myrowwitz, 1986) belong to the second category, called explicit semantic net hypertext systems. In these, users are provided with diagrams showing a part or the whole of the underlying structure network and rely heavily on the diagram for navigation (see Figure 2.2).

In the case of embedded semantic net hypertext, links are mainly represented by interactive buttons. The semantic relation conveyed by a link can be displayed by labelling the button representing the link with the expression of the relation. Since the buttons representing links are actually used as anchors of the links, the directions of the relations conveyed by the links are pointing outwards from the current node. The user in this case can only "see" a very small part of the underlying semantic net, i.e. that formed by the current node in the centre and those which connect to it directly, as illustrated in Figure 3.3. In fact, here, the user at the current node *Efficiency of Searching Tree*, can only see that there exist three nodes connected to it and the semantic relationships of those with the current node. The user has no indication of the contents of these nodes, even their names, until eventually jumping to them.

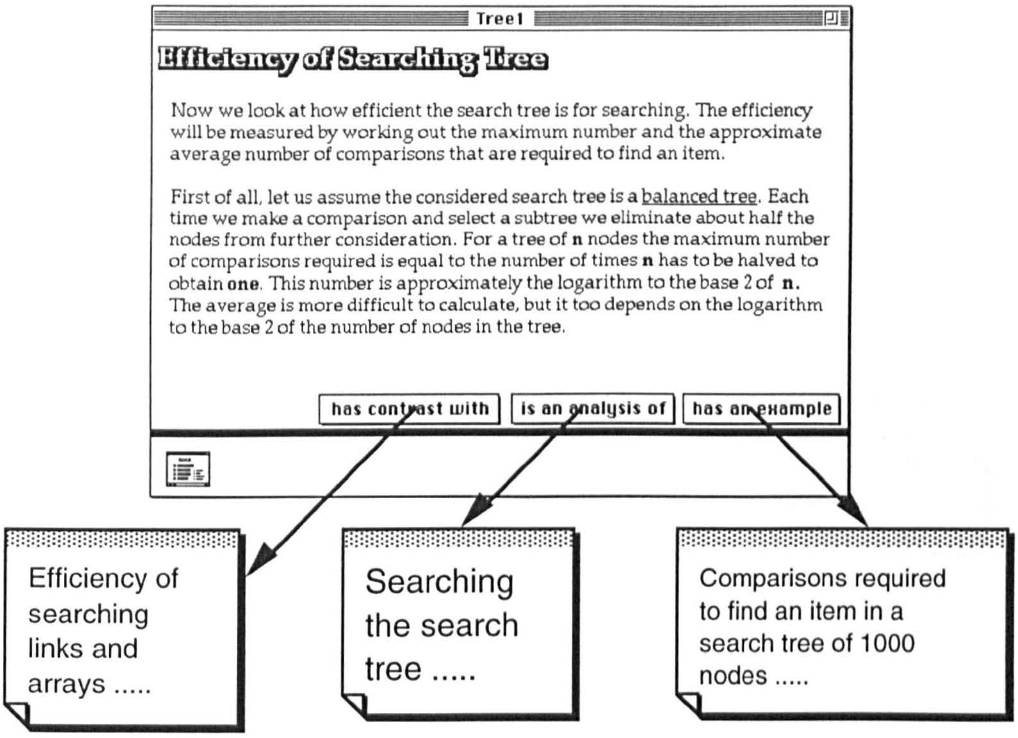

Figure 3.3 A simplified view of the embedded semantic net hypertext.

In the case of explicit semantic net hypertext, links are largely represented by lines between nodes in local and global structure diagrams. The semantic relation conveyed by a link can be made explicit in several different ways: directly attaching the expression of the relation to the linking line, using different colours or shapes of linking lines. The direction of the relation can be demonstrated by putting arrows on linking lines. In contrast to the embedded case, the user here is able to see the underlying semantic network more extensively and explicitly, as shown in Figure 3.4.

The rest of this section will be concerned with limitations of hypertext as a knowledge representation. There are two classes of limitations: limitations due to technical defects and limitations that seem to be endemic to hypertext as a knowledge representation. Limitations in the first class can be usually overcome by applying more sophisticated techniques while limitations belonging to the second class are difficult, if not impossible, to overcome.

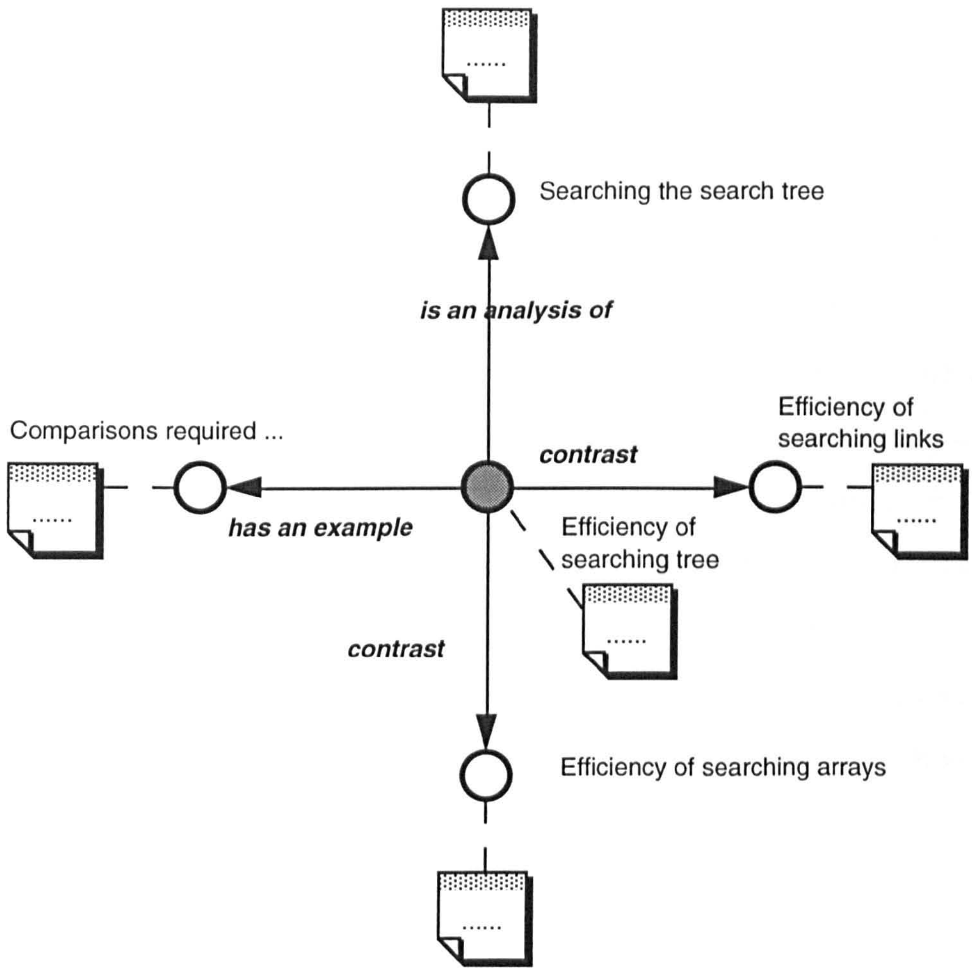

Figure 3.4 A simplified view of the explicit semantic net hypertext.

For example, relations vary in the ease with which they can be expressed. Some relations require only a short phrase, e.g., *is part of*, others require more elaborate expression. How to display those relations that need longer expressions becomes vital to our proposed approach, particularly when the number of links is large. This problem belongs to the first class of limitations, and will be examined in more detail in the final chapter of the thesis as a further research topic. The following are some limitations of the second class. Our discussion on semantic relations has been so far limited to binary relations, i.e., the relation between only two arguments. However, there exist in practice, semantic relations that relate to more than two concepts. For example, in the case of the sentence "John sold Mary a book", the relation *sell* has three arguments: *John*, *Mary*, and *a book*. The popular method of representing this kind of relation adopted in semantic networks is called *case representation*. Figure 3.5 shows how the above sentence is represented in such a method. A set of special relations such as *agent, recipient, patient* are introduced into this representation. More importantly, instead of the assertion of a fact being carried by a link between two nodes, the asserted fact is itself a node. It is obvious that when such a notation is applied to semantic network representations, a major restructuring of the network and what it means to be a link takes place (Woods, 1975). Unfortunately, this method is not suited to hypertext representations because the notation used in this method is so dissimilar to natural reading habits. The situation becomes even worse when this notation is used together with the notation introduced earlier for binary relations. In addition, the difficulties of semantic network representations, such as problems of relative clauses and quantification, would be encountered as obstacles if we wanted to go further in the direction of turning hypertext into a formal knowledge representation.

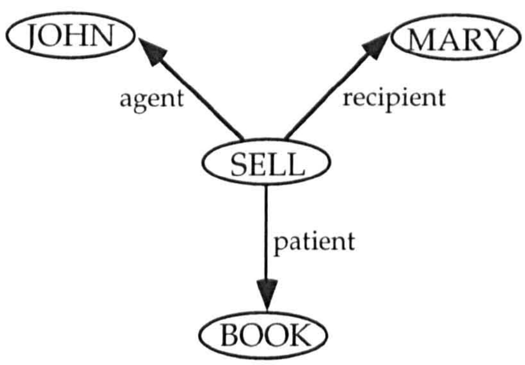

Figure 3.5 An example of the case representation in semantic networks.

3.8 Summary

The parallels between hypertext and semantic network representations, and cognitive learning theories have led us to hypothesise that labelling links explicitly with semantic relations between nodes might improve learning despite the limitations of hypertext as a knowledge representation. The next step is naturally to test this hypothesis. Before doing that, it is necessary to consider the ways of undertaking the task, more specifically the way to evaluate learning in hypertext-based learning environments. This will be the subject of our next chapter.

Chapter 4 Methodologies of Evaluation

4.1 Introduction

The methodology of evaluating hypertext-based learning is given in this chapter. In order to test the hypothesis described in Chapter 3, a multi-faceted approach to evaluation is adopted to assess hypertext-based learning from angles of both learning outcomes and learning processes. This approach consists of a set of data collection techniques and differing data analysis methods. The data collection techniques include multiple-choice questionnaires, teach-back tests, computer monitoring, think-aloud protocols, video-tapes and interviews. The data analysis methods include statistical analysis, graphical navigation pattern comparison, and interview protocol analysis. In addition to learning outcomes and learning processes, the learner satisfaction level is also considered.

4.2 Evaluation of Hypertext-Based Learning

Hypertext systems as learning environments have at least three features. They contain large amounts of information in varied formats; they provide high levels of learner control; and they facilitate interactions between learners and machines. Are such learning environments able to facilitate learning? Prior to finding the answer to this question, a method for evaluating learning with this new technology needs to be developed. Marchionini (1990) indicates that evaluations of hypertext-based learning must address both learning outcomes and learning processes, i.e., the product of learning as well as learner interactions with hypertext-based learning systems. Furthermore, he suggests a multi-faceted approach to such evaluations. This approach stems largely from the difficulty of evaluating learning processes. Since there are no proven methods for assessing the process of learning, we should observe and analyse the behavioural patterns exhibited during learning, from several perspectives. Thus, a multi-faceted evaluation approach was applied in our research to assess learning from two respects: learning outcomes, and learning processes.

Table 4.1 shows the multi-faceted toolkit used in our evaluation, including multiple-choice test, teach-back test, computer monitoring facility, think-aloud protocols, video-tapes, and interviews. They will be described in more detail in following subsections.

Table 4.1 A multi-faceted evaluation toolkit adopted in the research.

Evaluated Objects	Data Collection Methods	Data Types
Learning Outcomes	Multiple-choice questionnaire	Quantitative
	Teach-back test	Quantitative
Learning Processes	Monitoring scripts	Quantitative/Qualitative
	Think-aloud	Qualitative
	Video-tape	Qualitative
	Interview	Qualitative

4.2.1 Evaluation of Learning Outcomes

The typical method for assessing the outcome of a learning task is to measure learner performance on tests for that task. For well-defined learning tasks, like knowledge acquisition or motor skill development, teacher-made tests or standardised tests are considered valid and reliable indicators of learning outcomes. For open-ended objectives and higher levels of learning, tests of learning are more subjective and require additional steps to assure validity and reliability. The results of learner performance tests are normally of interval or ratio values (or can be transformed as such) so that powerful inferential statistical analysis can be employed to make generalisations about uniform impact.

In this research, multiple-choice questionnaires, in either printed or electronic form, were used to determine learning outcomes for goal-oriented learning tasks, and a combination of multiple-choice questionnaire and teach-back test was used to assess learning outcomes for the exploratory learning task. Different statistical methods were used to examine the reliability of the conclusions drawn from the test scores. The rest of this subsection will be devoted to the description of the teach-back test.

The teach-back testing technique was originally introduced by Pask and Scott (1972). The technique is simply described as: the student is asked to teach the experimenter whatever he has learned in the previous learning task on the assumption that the experimenter is a person of the same mental make-up as the student himself but is omniscient with respect to all relevant aspects of the task. Pask and Scott employed this technique to establish a student's competence in their study on the relationship of learning strategies and individual competence. A student's competence is his style or mental character presented in free learning conditions. According to Pask and Scott, there are two major types of learners in a free-learning task: holists, or global, learners and serialists, or step by step, learners, and the tenure of the competence type assigned on the basis of a student's free learning characteristics can be checked by a simple content analysis of teach-back protocol.

We used a combination of multiple-choice questionnaire and teach-back to assess the exploratory learning outcomes for the following reasons. Learning gains of subjects in exploratory learning conditions are likely to vary to a large extent due to subjects' different learning abilities, strategies and motivations, despite similar prior knowledge required by experiments. Moreover, students are also likely to learn not only discrete facts but also some comprehensive concepts in the exploratory learning task. It is obvious that the fixed multiple-choice questionnaire itself is inadequate to assess exploratory learning products. Instead, the teach-back test puts less constraint on the extent to which the learning products can be detected, and provides subjects with chances to reproduce the items they encountered during the acquisition period.

The verbal teach-back report can be transformed into quantitative data so that statistical analysis can be applied. The method used in the research will be described in detail in Chapter 6.

4.2.2 Evaluation of Learning Processes

According to Marchionini (1990), behavioural observations are obvious methods to use to deepen our understanding of learning with technology. An important assumption underlying the use of such methods is that human behaviour reflects cognitive processing. In the case of learning with hypertext, how learners interact with the system is the most important aspect of learning processes. A key point of interest in the research described in the thesis is learners' navigation patterns as well as a set of performance indicators. A navigation pattern is a classification assigned by the evaluator that is based on a set of navigation strategies exhibited by learners over learning sessions. The set of performance indicators include time spent on each node, total time spent on browsing, times certain types of links were activated, times certain types of navigational tools were employed. Navigation patterns and the set of performance indicators are important for several reasons. The major reason is that we desire to know how different interface designs, i.e., visualising semantic relations between nodes or not, affect the learner behaviour in navigating through hypertext documents. The secondary reason is that we are also interested in identifying what kinds of learners navigate in what kinds of ways and how learners' navigation is influenced by learning tasks. The navigation patterns and the set of performance indicators, in our studies, are built from behavioural data collected by the hypertext system itself, and complemented and explained by the data collected on video and audio tapes as well as from interviews. We will discuss these data collection methods in the rest of this subsection.

Monitoring Scripts

A wealth of data regarding user behaviour can be easily collected within many hypertext development environments. Developers of hypertext systems are usually provided by such environments with possibilities of building functions to capture and time-stamp actions taken by users, such as keystrokes, mouse clicks, and mouse moves. In our experimental hypertext systems, which were implemented in HyperCard (Harvey, 1989) (a brief description of this hypertext authoring package can be found in the next chapter), such functions are realised by monitoring scripts. The computer data collection method has the advantages of being unobtrusive, unbiased, accurate, consistent, and inexpensive.

Figure 4.1 shows a sample student's behavioural data captured by monitoring scripts in one of our hypertext systems over a learning session. It includes the student's name (asked for at the beginning of the session), date of the experiment, starting time, name of each card, time spent (minute:second) on each card, and the way of leaving the current card. Values for a set of performance indicators are calculated when the session is over. These are the length of session, number of cards browsed, number of different cards browsed and number of times that the student used the four different methods of jumping.

```
**** Records of Users' Navigation Path ****
USER NAME:
STARTING TIME:   2:30 pm   5/11/92
==========================================
CARD:   lists
ELAPSED TIME:   2:6
Leaving this card through LOCAL DIAGRAM
-----------------------
CARD:   static lists
ELAPSED TIME:   1:29
Leaving this card through LOCAL DIAGRAM
-----------------------
CARD:   dynamic lists
ELAPSED TIME:   0:48
Leaving this card through GO BACK
-----------------------
CARD:   static lists
ELAPSED TIME:   0:10
Leaving this card through LOCAL DIAGRAM
-----------------------
CARD:   dynamic lists
ELAPSED TIME:   0:57
Leaving this card through LOCAL DIAGRAM
-----------------------
CARD:   lists
ELAPSED TIME:   0:5
Leaving this card through LOCAL DIAGRAM
-----------------------
CARD:   dynamic lists
ELAPSED TIME:   0:7
Leaving this card through LOCAL DIAGRAM
-----------------------
    .
    .
    .
    .
CARD:   arrays
ELAPSED TIME:   0:3
Leaving this card through LOCAL DIAGRAM
-----------------------
CARD:   static lists
ELAPSED TIME:   0:7
Leaving this card through LOCAL DIAGRAM
-----------------------
CARD:   lists
ELAPSED TIME:   0:19
==========================================
ENDING TIME:   3:23 pm   5/11/92
BROWSING TIME:   53 mins 13 secs
CARDS BROWSED:   71
DIFFERENT CARDS BROWSED:   22
TIMES OF JUMPING THROUGH "GO RECENT":   0
TIMES OF JUMPING THROUGH "GO BACK":   11
TIMES OF JUMPING THROUGH "INDEX":   0
TIMES OF JUMPING THROUGH "DIAGRAM":   59
```

Figure 4.1 A sample student's behavioural data collected by monitoring scripts.

```
on makeRecord
  global startT, theCurrentNode, howJump
  put the seconds - startT into elapsedT
  put elapsedT div 60 into elapsedM
  put elapsedT mod 60 into elapsedS
  if the length of cd fld "Record" of cd "RecordCard" < 29980
  then
    put "------------------------" & return after cd fld "Record" of cd "RecordCard"
    put "CARD:" && space && theCurrentNode & return after cd fld "Record" of cd "RecordCard"
    put "ELAPSED TIME:" && space && elapsedM & ":" & elapsedS & return ¬
    after cd fld "Record" of cd "RecordCard"
    if howJump = 1 then
      put "Leaving this card through GO RECENT" & return ¬
      after cd fld "Record" of cd "RecordCard"
    else
      if howJump = 2 then
        put "Leaving this card through GO BACK" & return ¬
        after cd fld "Record" of cd "RecordCard"
      else
        if howJump = 3 then
          put "Leaving this card through INDEX" & return ¬
          after cd fld "Record" of cd "RecordCard"
        else
          if howJump = 4 then
            put "Leaving this card through LOCAL DIAGRAM" & return ¬
            after cd fld "Record" of cd "RecordCard"
          end if
        end if
      end if
    end if
  else
    put empty into cd fld "Record" of cd "RecordCard"
  end if
end makeRecord
```

Figure 4.2 The main part of monitoring scripts.

The monitoring scripts fulfilling such data collection functions are not complex largely due to the object-oriented nature of HyperCard. The main function for monitoring scripts in HyperTalk (Winkler & Kamins, 1990), the programming language of HyperCard, is shown in Figure 4.2. This is a user-defined message handler (corresponding to the user-defined function in C) called from the system message handler *closeCard* (corresponding to a piece of main program in C). Because both this handler and its host *closeCard* are placed at the stack level, and there is no other handler named *closeCard* associated with objects down in the message passing path, this handler is activated every time a card is closed. The value of global variable *startT* is the time when the current card was opened, which was assigned in the system message handler *openCard*. Obviously, the time difference between card opening and closing means the time spent on the current card. The value of global variable *howJump* can be one of 1, 2, 3, 4, 0 according to which method the student chose (i.e., which button was clicked) to leave the current card. The system provides five ways to move from one card to another: *GO RECENT, GO BACK, INDEX, LOCAL DIAGRAM,* and methods allowed by HyperCard itself. All data is stored in a container called the *Record* field. The container is held on a special card *RecordCard*, the last card of the stack, as seen in Figure 4.3.

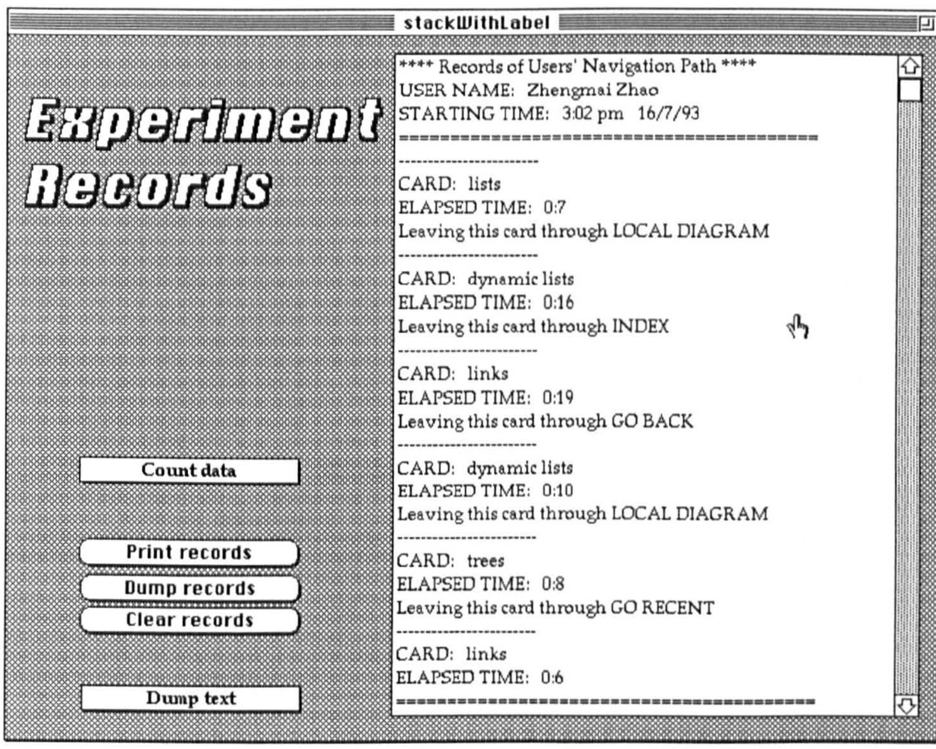

Figure 4.3 The card that holds the learner's behavioural data.

Working out values for the set of performance indicators is relatively simple. For example, the times of jumping through diagram are formed by adding 1 to the value of a global variable every time an active line in the local structure diagram is clicked. Both descriptive and inferential statistical methods can be used to analyse the data contained in these indicators as they are quantitative. However, building up navigation patterns from the captured data is rather more difficult. Little research has been done on methodologies for analysing patterns of user interactions with hypertext systems (Nelson, Harmon, Orey, & Palumbo, 1993), although the method of evaluating the use of general information systems has been well developed (Penniman, & Dominck, 1980).

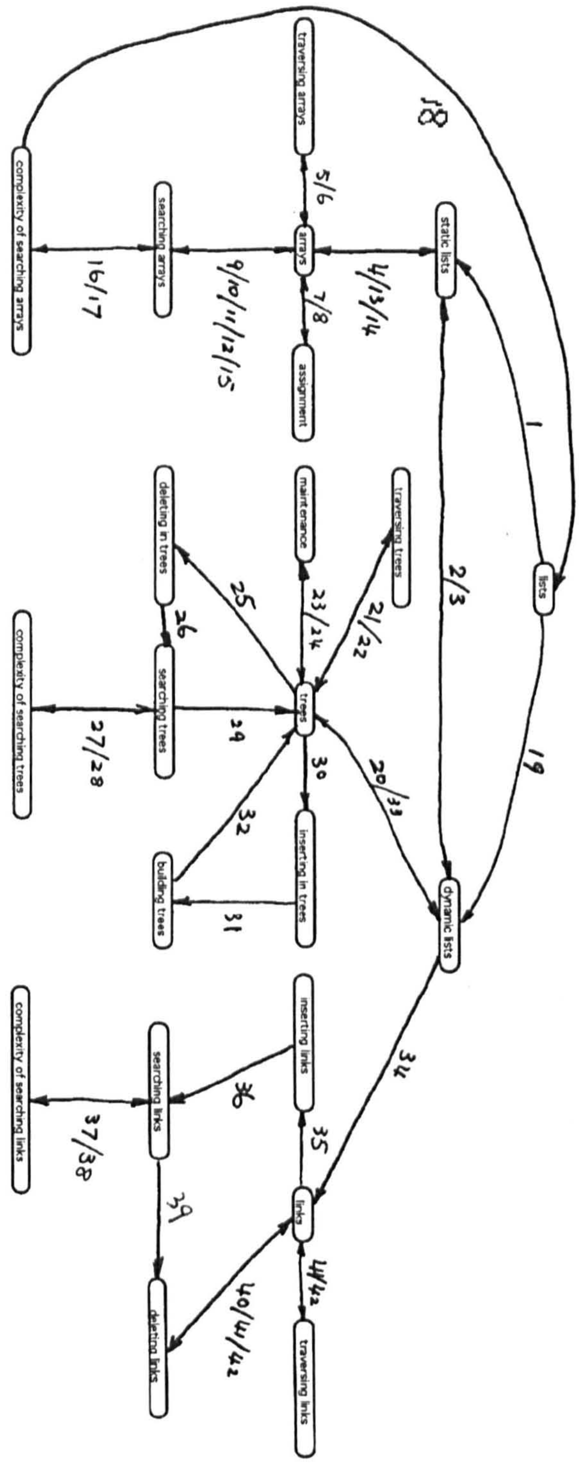

Figure 4.4 The graphic representation of the navigation path.

The method we used is to produce graphic representations of the data to allow visual comparisons to be made by the evaluator. More specifically, the computer captured navigation path for each student (see Figure 4.1 as an example) would be transformed manually into a directed graph (see Figure 4.4 as an example), where directional arcs represent links followed by users and the numbers attached to arcs represent the sequence of jumping. An arc attached to more than one sequencing number means that it was activated more than once. Obviously, this method will become less practical when the scale of navigation path increases. It is not difficult for computers to do the job, i.e., to create such a graphical traces of user navigation automatically. This issue will be discussed in more detail as part of further work in the final chapter.

Think-aloud, Video-tape, and Interview

Navigation path tracking has the benefit of providing an objective description of user behaviour, but provides little or no insight into user perspective. Did a user jump from one node to another because she/he was interested in that topic? Or perhaps because she/he was avoiding another node? Or perhaps because s/he was confused, or lost? Did a user stay in a node longer because he had difficulty in reading or understanding the current topic? Or perhaps because s/he was having a short break? Or perhaps because s/he needed time to decide which link to follow next? The think-aloud method is intended to help evaluators in probing the user's cognitive processes. Two kinds of think-aloud techniques are normally used. One is asking subjects to verbalise their thoughts as they learn, and the other is eliciting learner commentary at critical decision points. The former was adopted in our research because we thought that compared with the latter it would interfere less with user interaction. The verbal think-aloud reports were recorded by a video camera together with the scenes where the think-aloud was happening. The camera was placed in a fixed position to the screen with no operator present during study-time. The main purpose of video-taping the screen in the experiments is to make the subsequent analysis of think-aloud data easier. The task of capturing user behavioural data was fulfilled by the embedded monitoring scripts as described earlier.

The think-aloud approach has two drawbacks. First, the very process of verbalising their cogitations may unduly influence users' learning. Secondly, the subjects may not be willing or able to verbalise their thoughts as they participate in the research. Interviews, on the other hand, reduce these problems since they do not interfere with user interaction and allow the subject more time to verbalise their thoughts. In our research, interviews with individuals about aspects of their navigation strategies were conducted after the learning session. The data collected by both interviews and think-aloud are believed to be valuable sources of information about cognitive processes (Ericsson & Simon, 1980; Kerlinger, 1973). Each of them contributes in a different way to our insight into user perspective. Therefore, both of them are included in our multi-faceted evaluation toolkit.

4.3 Usability of Hypertext-Based Learning Systems

Usability is usually associated with five dimensions (Nielsen, 1990a):

Easy to learn:	The user can quickly get some work done with the system.
Efficient to use:	Once the user has learned to use the system, a high level of productivity is possible.
Easy to remember:	The casual user is able to return to the system after some period without having to learn everything again.
Few errors:	Users do not make many errors during the use of the system, or if they do, they can easily recover from them.
Pleasant to use:	Users are subjectively satisfied by using the system.

For a hypertext system for learning, the evaluation of learning outcomes and processes discussed in the last section touches upon only one of the five usability parameters, i.e., the efficiency of use. In order to understand better the effectiveness of our proposed approach, i.e., visualisation of semantic relations between nodes in hypertext-based learning systems, we have also examined the influence of different interface designs on learner subjective satisfaction. It must be noted that the subjective satisfaction usability parameter is not always positively correlated with the efficiency parameter. In fact, among the five usability parameters listed above, none of them is a predictor for any of the others.

The standard method of measuring user satisfaction is by asking the users themselves to report their satisfaction. This was achieved in our research by questionnaires and interviews. The questionnaire was designed to elicit users' attitudes on a 4- or 5-point scale towards the use of system (e.g. How did you enjoy using this hypertext system? with a 4-point scale from "Very much" to "Not at all"), and towards specific interface element design (e.g. What do you think of the way a hotpoint was represented in the textual area? with a 5-point scale from "Very good" to "Very poor"). Subjects' responses to these questionnaires could be easily transformed into quantitative data for both descriptive and inferential statistical analysis. The interview had two main functions: providing insight into user perception of systems, and giving subjects the chance to voice opinions about things not mentioned in the questionnaire, or about more general themes or topics.

4.4 Summary

This chapter has outlined the method used in evaluating hypertext-based learning in this thesis. Platforms, i.e., experimental hypertext systems, are needed to be built before the testing can really proceed. The next chapter will be concerned with the design and implementation of such platforms.

Chapter 5 Experimental Hypertext Systems

5.1 Introduction

This chapter describes the development of the experimental hypertext systems used in the studies. It includes reasons for the selection of learning materials and authoring tools, the design of information models and user interfaces, and some implementation techniques. It must be indicated that our emphasis was on producing the hypertext systems which satisfy our specific research criteria and not on developing all-purpose systems.

5.2 Learning Materials

The learning material contained in the experimental hypertext systems is adapted from the course book of the Open University course M205: "Fundamentals of Computing", Block IV: "Data Structures". However, the hyperdocument involves only a subset of the block (i.e., "lists"), and the theme is described at an abstract level rather than at the level of actual programming so that little prior knowledge and experience of programming is needed to understand the content. The hyperdocument can be abstracted as follows:

> The list is one of commonly-used, complex data structures. A list can be either static or dynamic according to whether or not the number of items included in the list will be changed. The static list is normally represented by using arrays whereas the dynamic list can be represented by either trees or links chiefly based upon the scale of the list. Each data representation is associated with a set of operations. Although the three operation sets are different, they all include the searching operation. Searching is the most important operation of all, and its efficiency is normally measured by its complexity. The efficiency of searching operation is one of the most important factors for choice of data representation.

The above subject was chosen as our experimental learning material for the following two reasons. Firstly, the nature of the research question requires that the knowledge structure underlying the experimental hyperdocument must be of a certain degree of complexity. The hypertext is used for detecting whether visualisation of semantic relations between nodes helps users navigate through the knowledge structure, thus, facilitating understanding of the knowledge domain. The underlying structure of the selected knowledge domain is complex enough for this purpose. For example, selecting an appropriate data representation for a list depends on many parameters such as whether the scale of the list changes or not, how large the scale is, what kinds of operations are required to be performed on the list, and how efficient the major operations are. Secondly, the author of this thesis comes from a computing background, and is used to teaching the chosen subject. Being both a domain expert and hypertext engineer is of benefit in not only reducing the time period of system development but also in improving the quality of the system.

5.3 Hypertext Authoring Tools

In implementing the experimental hypertext systems, HyperCard 2.1 was used as the authoring tool. In addition, QuickTime 1.6 was incorporated to let the hypertext user see and manipulate, to some extent, some dynamic events included in the selected learning material (e.g., the procedures of building and traversing search trees).

5.3.1 HyperCard and HyperTalk

Several hypertext authoring systems are available for use on Apple Macintosh machines (a Mac IIci with 1152×870 monochrome screen was the target platform for this research) such as HyperCard, Guide, Plus, and SuperCard. HyperCard was finally selected for the following reasons. The chosen authoring system should be able to allow the designer to customise the user interface within a certain framework as the research focuses on the interface design. In addition, the system should also provide the possibility of allowing the resulting hypertext to incorporate not only text but graphics and animation since they are essential to represent the selected knowledge domain described in the previous section.

The plain engine of Guide is not capable of meeting these requirements. What the author of Guide can do is solely to input text into the system after which the system takes care of everything else. For example, pop-up menus in Guide always appear in the top right corner of the screen. The author has no way to make any user interface decisions except for a few low-level formatting details such as where to break paragraphs.

Although the remaining packages investigated (HyperCard, SuperCard, and Plus) all satisfy the above two technical demands, HyperCard is the strongest candidate. Since HyperCard has been bundled free with every Macintosh machine sold by Apple since its introduction in 1987, it has a large number of users all over the world. More technical support is available for HyperCard than for the other two packages. For example, a number of remote archive servers over JANET and Internet networks contain shareware or freeware HyperCard stacks, utilities, externals, and information for HyperCard programmers. These can be easily downloaded by using anonymous FTP (File Transfer Protocol). The most popular such archive has been the info-Mac Archive at *sumex-aim.stanford.edu*. In addition there are a number of Listserv Lists (or listservers) dedicated to various issues in relation to HyperCard, which allow electronic discussion of technical and non-technical issues to be conducted by electronic mail over BITNET using LISTSERV protocols. The author of this thesis has subscribed to such a list called HYPERCRD located in site MSU (Michigan State University, USA) on BITNET, and has benefited much from the access to these supports in developing the experimental hypertext systems. One example is that many useful suggestions were received from HYPERCRD about where to display a graphical browser. The methods suggested include using two separate stacks positioned side by side, incorporating both graphical browser and contents on a large card, placing the browser on a palette created by the *Palette Maker* in the Power Tools, and employing two copies of HyperCard that can be made to communicate to each other by sending and receiving the *appleEvent* message under System 7. Another example is that a number of externals downloaded from remote archive servers were incorporated into the experimental systems in order to include some functions which are impossible or inefficient to implement using the basic HyperCard.

As the name implies, HyperCard is strongly based on the card metaphor. A card is the basic unit of organisation in HyperCard. A collection of cards is called a HyperCard stack. Cards in a stack can be linked together in various ways although they are physically stored in the memory in sequence. A card can hold formatted text in field objects, graphics created by means of graphic tools, and buttons/icons which function mainly as anchors of links. HyperCard includes a general programming language known as HyperTalk. HyperTalk programs, usually called scripts, are sets of message handlers that are attached to HyperCard objects such as buttons, fields, and cards. HyperCard sends standard messages to these scripts along a well-defined path, allowing them to respond to user events such as mouse clicks and key-presses and to state changes such as transitions between cards. The scripting language provides a rich set of functions, including operations on numbers, strings, and dates, operations on data stored within stacks, and manipulations of interface objects.

However, both HyperCard and its built-in programming language, HyperTalk, have obvious limitations in many aspects. Here are just a few examples. Apart from a relatively limited number of graphical interface elements (i.e., buttons, icons, and editable text fields with only vertical scrollbars), some commonly-used elements such as pop-up menus and even horizontal scrollbars are not available within the basic

HyperCard framework. In addition, there is no direct access to some aspects of the hardware or operating system from the standard built-in HyperTalk.

Fortunately, HyperTalk supports a mechanism for calling code resources by name with parameters and retrieving results from them. This mechanism allows the possibility of supplementing the functionality of the HyperTalk language and HyperCard as well. These code resources are referred to as externals, including XCMD (external command) and XFCN (external function). An XCMD acts as a command added to HyperTalk's vocabulary, which is normally written in C or Pascal and glued into HyperCard. An XFCN is the same as an XCMD except it is a function that returns a value rather than a command that is not expected to return a result. Large libraries of externals are now available for a wide variety of purposes, from playing QuickTime movies to converting tabs in tab-delimited text to spaces. We have incorporated a number of externals into our experimental hypertext stacks to realise our special design requirements. Details about HyperCard and HyperTalk can be found in Winkler & Kamins, 1990; Shafer, 1988; and Harvey, 1989.

5.3.2 QuickTime

QuickTime is the Macintosh system software extension that enables programmers to create multimedia applications with sound, video, and animation (Hone, 1993; Miller & Harris, 1993). However, its strength is in processing video images. QuickTime makes it possible for the first time for video to be displayed and edited on a Macintosh computer, although at least a Macintosh IIci under System 7 with 8MB of RAM and considerable space on the hard disk is needed. Even so, we found that QuickTime was more suitable for our animation purpose compared with the ways of animating images provided by HyperCard itself. The reason lies in the fact that it is easier for developers to facilitate user direct manipulation of animation in QuickTime than in HyperCard animation. This is because every QuickTime movie (in our case, the movie is animation) is automatically attached with a movie controller at the bottom of its window, which allows, when visible, users to control the actions of a movie (see Figure 5.1). The *Play* button is used to start the movie. Once the movie is playing, this button becomes a *Pause* button, allowing the user to stop the movie. The *Step Backward* and *Step Forward* buttons allow users to move the movie forward or backward one frame at a time. With the *Slider* bar, users are able to quickly move to any point in the movie. The *Volume* control button allows adjusting the audio volume, although this is not currently applicable to our systems.

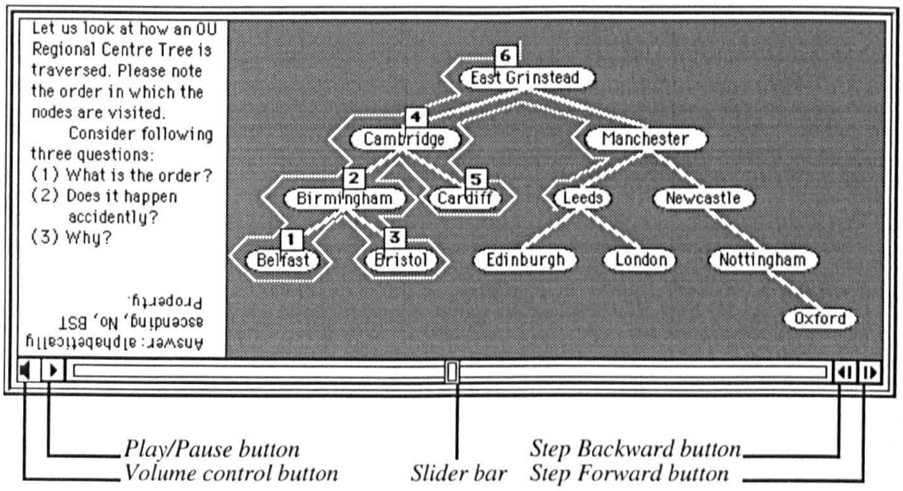

Figure 5.1 An illustration of the movie controller.

QuickTime movies are usually created from videotapes. A number of products, called video capture boards (e.g., Supermac Technology's VideoSpigot, and RasterOps' 24STV Video Adapter), digitise video segments and store them as QuickTime movies. The QuickTime animation used in our systems was created in a different way. First of all, a sequence of PICT files was created, using a graphics package. Then, a software package, called Convert To Movies, was used to convert the sequence of PICT files into QuickTime movies. There exist a number of programs (e.g., MoviePlayer, Simple Player, etc.) which allow users to open, play, and even edit QuickTime movies. However, externals are needed to undertake these tasks within HyperCard since the basic HyperCard framework does not include this functionality as pointed out before. An XCMD called *Movie* was installed in the resource fork of our stacks to let users see and play the animation. The external is created by Claris Corporation, and delivered with a freeware HyperCard stack named QuickTime Tools available on many anonymous network archive servers. Figure 5.2 shows a handler which opens the QuickTime animation by calling the *Movie* XCMD. The command has five parameters: *File name, Window Style, Location, Visible, and Layering*. More specifically, the five parameters are intended to elicit, respectively, the name of the QuickTime file to be displayed, the style of window in which the movie is displayed, the location at which the movie window will be displayed, the indication of whether the movie window is initially visible, and what kind of layer the movie window will be.

```
on mouseUp
  global theExampleName
  play "press"
  set cursor to busy
  put "treesTrav.MooV" into theExampleName
  if theExampleName is in the windows then
    close window theExampleName
    set the name of me to "(see an example)"
  else
    Movie theExampleName,"dialog","300,480","visible","floating"
    set the name of me to "(hide the example)"
  end if
end mouseUp
```

Figure 5.2 A handler opening/closing a QuickTime movie window.

5.4 An Embedded Semantic Net Hypertext System

As defined in Chapter 3, embedded semantic net hypertext systems are those hypertext systems in which no structure diagrams are provided for navigation. Two versions of an embedded semantic net hypertext system were developed for our study. These will be referred to as embedded Visible Link-Types (VLTs) and embedded No Visible Link-Types (NoVLTs). In describing these two versions of the embedded semantic net hypertext system developed, we shall first cover the features general to both versions, then discuss the characteristics particular to each.

5.4.1 System Design

Two major issues have been particularly considered in designing the experimental hypertext system. These are information model design and user interface design.

Information Model Design

This issue is concerned with how to structure information in the hypertext knowledge base. Basically, there are three types of hypertext structures: node-links, hierarchies, and networks (Jonassen, 1986, 1988; Jonassen & Grabinger, 1990; Martin, 1990; Woodhead, 1991).

The node-link structure is the least structured. There exists a direct link between any two distinct nodes in this type of structure, so that the user of the hypertext is provided with random access directly from one node to any other node. This kind of structure can be illustrated as a complete graph (Figure 5.3). Obviously, no overall conceptual structure is necessarily implied by the hypertext with a node-link structure.

The hierarchical structure is the most highly structured. Here, the information in this structure is organised in such a way that general concepts are broken down into more detailed concepts which are instantiated by individual events or objects. Knowledge domains in science usually possess hierarchical structures (e.g. the plant kingdom). Such a structure can be represented by a tree (Figure 5.4). The user of the hypertext with such a kind of structure is required to move up and down through the hierarchy in order to access related concepts. It is clear that there should be a starting point in the structure, that is, the node representing the most general concept. This node is normally the first one displayed to users.

The network structure implies a subject matter structure or a knowledge structure that ought to be conveyed in the links between the nodes as does the hierarchical structure. There are two common topologies of network structure (Figure 5.5). The first one consists of sets of nodes, each set accessible from any other set. The node sets can have different structures (e.g. hierarchy, sequence, network, etc.), depending on the nature of the sub-domain. If each node set shrinks into a point then the whole structure is turned into a node-link structure. The second one is similar to a hierarchy but with cross-links. Like the hierarchical structure, there is also a starting node in this structure.

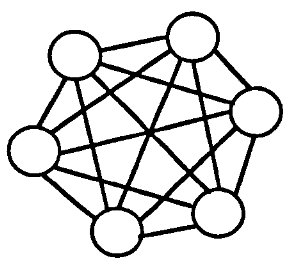

Figure 5.3 A node-link structure.

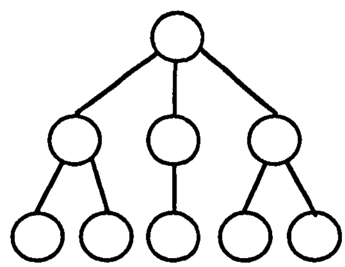

Figure 5.4 A hierarchical structure.

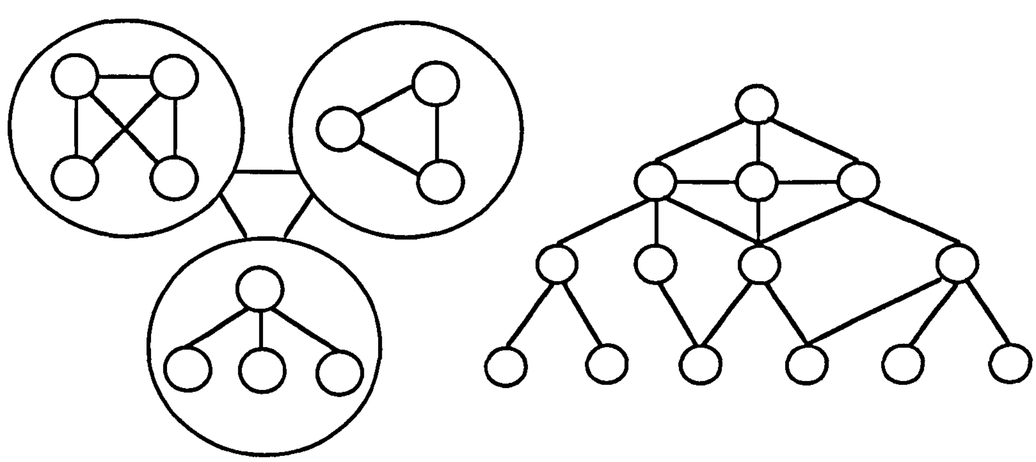

Figure 5.5 Two common types of network structures.

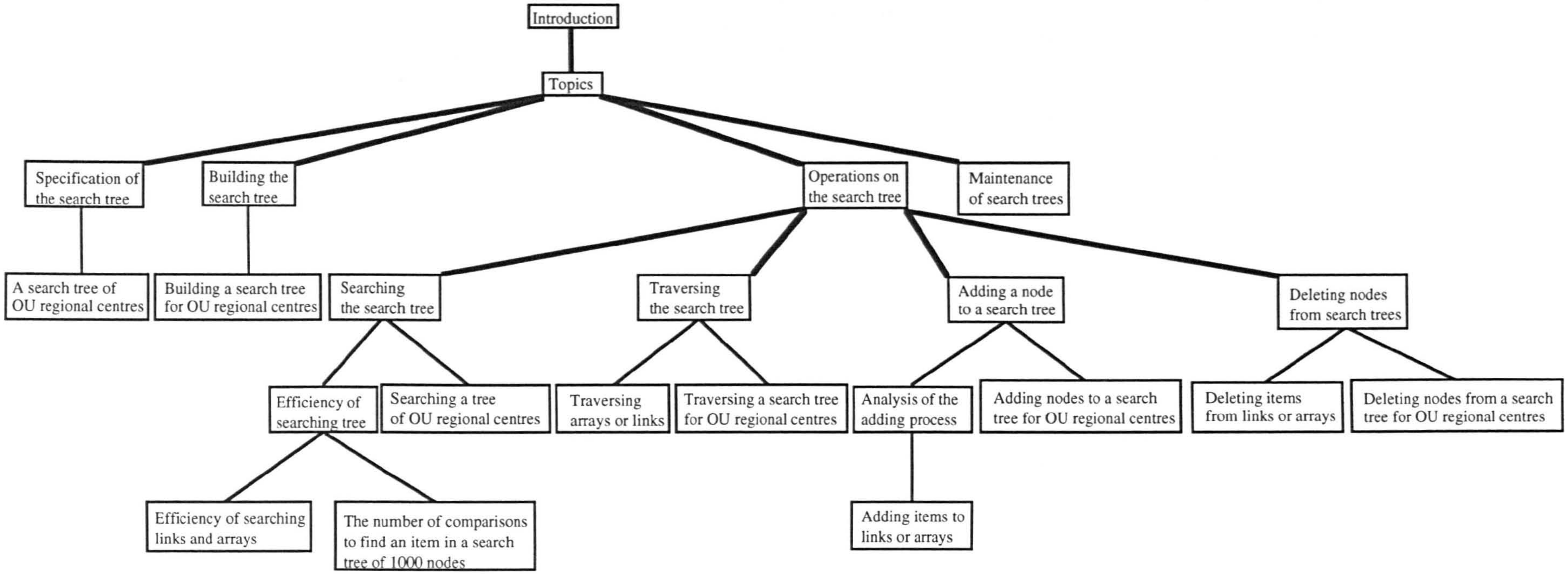

Figure 5.6 The structure of the embedded semantic net hypertext system.

The structure chosen for our embedded semantic net hypertext is hierarchical (Figure 5.6). It is determined by the author, based on his understanding of the learning materials and his personal tastes. This method of designing the information model for hypertext learning systems, according to Jonassen and Grabinger (1990), is the deductive or top-down approach. The rationale for this approach lies in the assumption that "learning is the process of replicating the expert's knowledge structure in the learner's knowledge structure" (Jonassen & Grabinger, 1990). The opposite of this method is the inductive or bottom-up approach, in which the hypertext structure is decided by observing users' navigation patterns through the least structured, node-link hypertext.

There are two kinds of links that are used to build the structure for the hypertext knowledge base. The links represented by thick lines in the figure are called organisational links. Such links as *Start from the beginning*, *Go to the topic menu*, and links from entries of the topic menu to their sections fall into this category. The links represented by thin lines in the figure are called associative links. Two nodes are linked to each other by an associative link based on their semantic relationships as defined earlier in Chapter 3. All lines imply two-way links, that is, if there is a link from node **A** to **B** then there must exist a link from node **B** to **A**. In addition to organisational and associative links, there is another kind of link, namely referential links, in the hypertext. The referential link defined in our system is directed, although the *backward* movement along the link is always allowed. The origin of the link is a marked textual string (also referred to as a *hotpoint*), and acts as the *reference*. The destination of the link is a node, and functions as the *referent*. Referential links are not shown in the structure diagram as they have less influence on the basic conceptual structure of the hypertext.

User Interface Design

Facilitating users' navigation through hypertext is the central issue in designing the user interface for hypertext systems. How the interface should be designed to help users navigate so that learning with hypertext can be enhanced is the main concern of our research.

The physical appearance of nodes is rather simple. Figure 5.7 shows what a typical node looks like. It contains a thematic title that is elaborated by a text passage (accompanied by graphics or animation in some cases). The anchor of associative links is represented by the labelled button placed below the text passage but above the thick black line, whereas the icon under the line represents the organisational link. The origin of the referential link is denoted by the textual string with an underline.

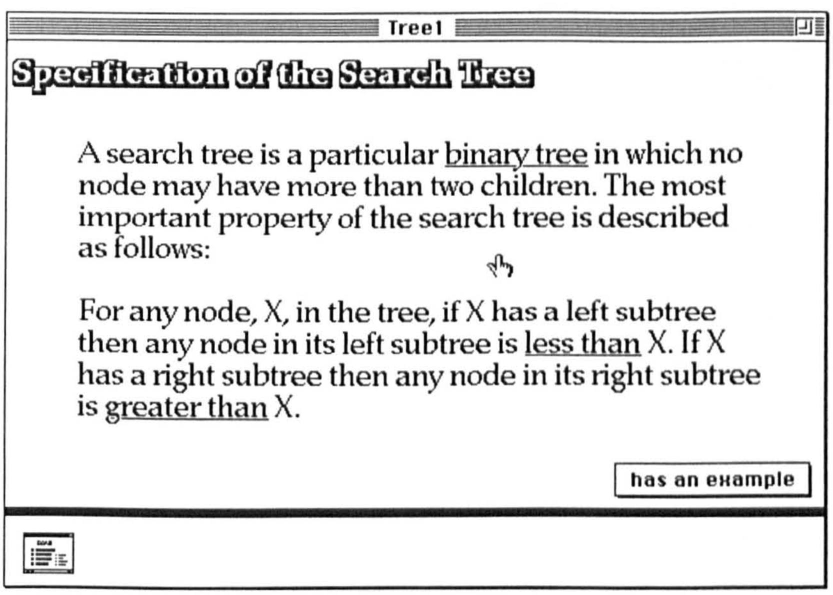

Figure 5.7 An example node of the embedded semantic net hypertext.

Two versions of this hypertext were used in the study. They differ from each other in the way in which associative and referential links are denoted. In the VLTs version, the associative link is labelled explicitly by using the name of the semantic relation between the two nodes it connects such as *has an example*, *is an example of*, *contrasts* *with*, *has an analysis*, *is an analysis of*, and so forth (see Figure 5.8). In the case of the referential link, every link origin embedded within the text passage has a small information palette attached. Once the user moves the cursor over a *hotpoint*, it is highlighted and its palette with information about the semantic relationship between the reference and its referent appears at the bottom of the card (see also Figure 5.8). When the cursor is moved out of the *hotpoint*, it is restored to normal and simultaneously its palette disappears.

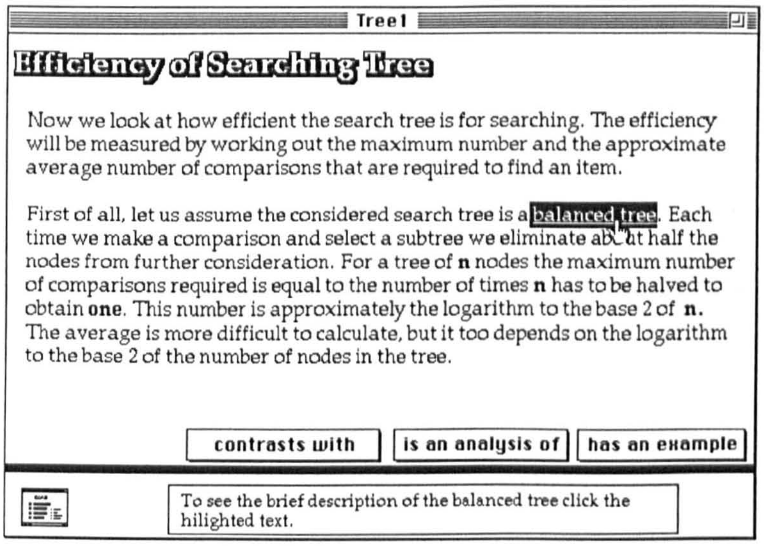

Figure 5.8 An example of denoting associative and referential links in VLTs.

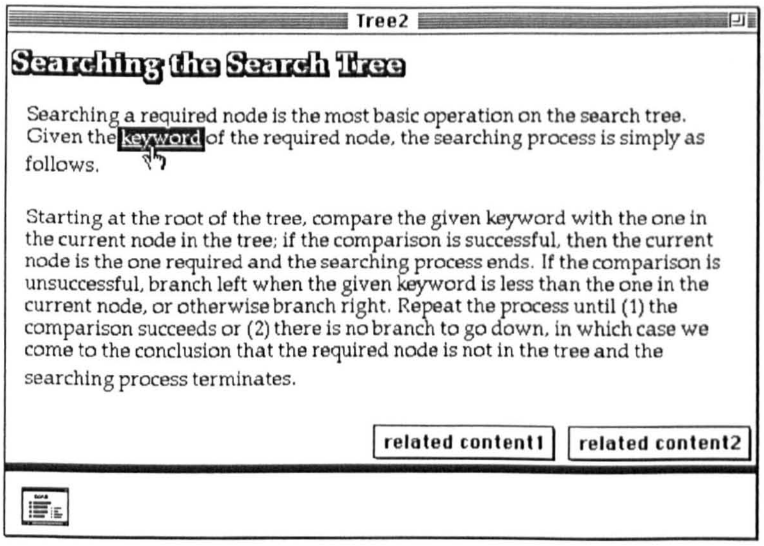

Figure 5.9 An example of denoting associative and referential links in NoVLTs.

In contrast to this, in the NoVLTs version, all associative links are labelled as *related content.* Users can see how many associative links emanate from the current node, but see neither the thematic titles of those associated nodes nor the semantic relationships between them and the current node. In the referential link, no palette with the semantic relation information is attached to the *hotpoint*. Figure 5.9 shows an example node of NoVLTs.

5.4.2 System Implementation

The system was implemented on an Macintosh with HyperCard 2.1 as the authoring tool. It comprises thirty-four 512×342 cards and approximately one-hundred links, two thousand words, and a dozen instances of graphics and animation. The whole hypertext system, including a HyperCard stack and an accompanying QuickTime file, takes about 200Kbytes on hard disk. The system has good response time.

5.5 An Explicit Semantic Net Hypertext System

As defined in Chapter 3, explicit semantic net hypertext systems are those hypertext systems in which structure diagrams are provided for navigation. Two versions of an explicit semantic net hypertext system were developed for our study. They will be referred to as explicit Visible Link-Types (VLTs) and explicit No Visible Link-Types (NoVLTs). In describing these two versions of the explicit semantic net hypertext system developed, we shall first cover the features common to both versions, then discuss the characteristics particular to each.

5.5.1 System Design

As before, two major issues have been particularly considered in designing the experimental hypertext system: information model design and user interface design.

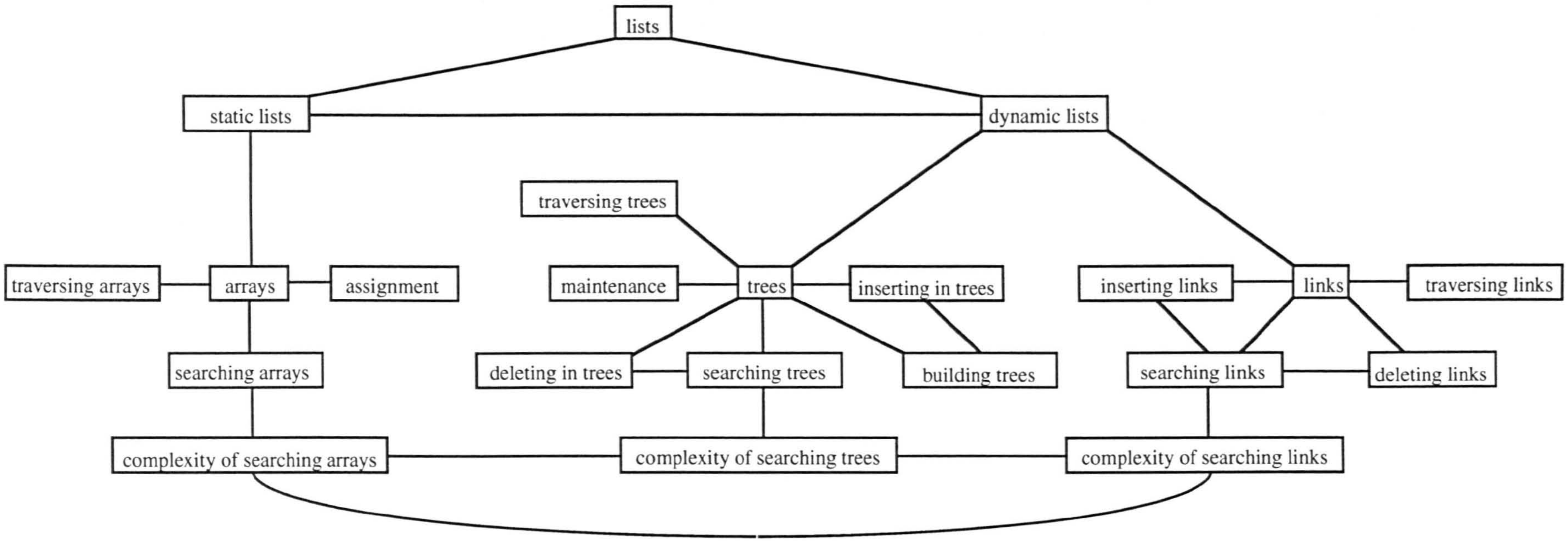

Figure 5.10 The structure of the explicit semantic net hypertext system.

Information Model Design

The knowledge domain covered by this hypertext is larger than that covered by the first hypertext described in the last section. Instead of one data structure (the search tree) introduced in the previous hypertext, three different data structures (arrays, links, and trees) are described and compared. A hierarchical structure is obviously not sufficient to facilitate the comparisons among these three data structures. Therefore, the information in this hypertext is organised as the second type of network structure described in the last section, that is, a hierarchy with cross-links (see Figure 5.10). Only one type of link (i.e., associative links) is used to build the hypertext information structure. However, there are two other types of link, which have less influence on the basic conceptual structure of the hypertext. One is the referential link, the other is the implicit link functioning through the use of such facilities as the index, backtracking, and history trail, which will be detailed later on.

User Interface Design

As stated in the last section, the chief consideration in designing user interfaces for hypertext systems is the user navigation through hypertext. In this hypertext system, structure diagrams, index, backtracking, and history trail are used as navigational aids. Before going into details of these facilities, let us first have an overview of the interface. Figure 5.11 shows the physical appearance of a typical node.

A card is divided into two main areas: text area and navigation area. The text area contains a thematic title that is elaborated by a text passage. Two types of footnote-like referential links can be found in the text area. One is indicated by the *hotpoint* (the underlined textual string embedded within the text passage). A small textual window will pop up when a *hotpoint* is pressed down. The other kind of referential links is anchored by the *see* ··· imperative sentence, which is normally placed below the text passage. Once such a bracketed bold and italic sentence is clicked, a floating window appears, which contains graphics or animation as supplement to the text. The navigation area can be further broken down into two parts: the structure diagram and a set of navigational tools. The former consists of both global and local structure diagrams, and the latter comprises index, backtracking, history trail, and balloon help. They will be described in more detail in the rest of this subsection.

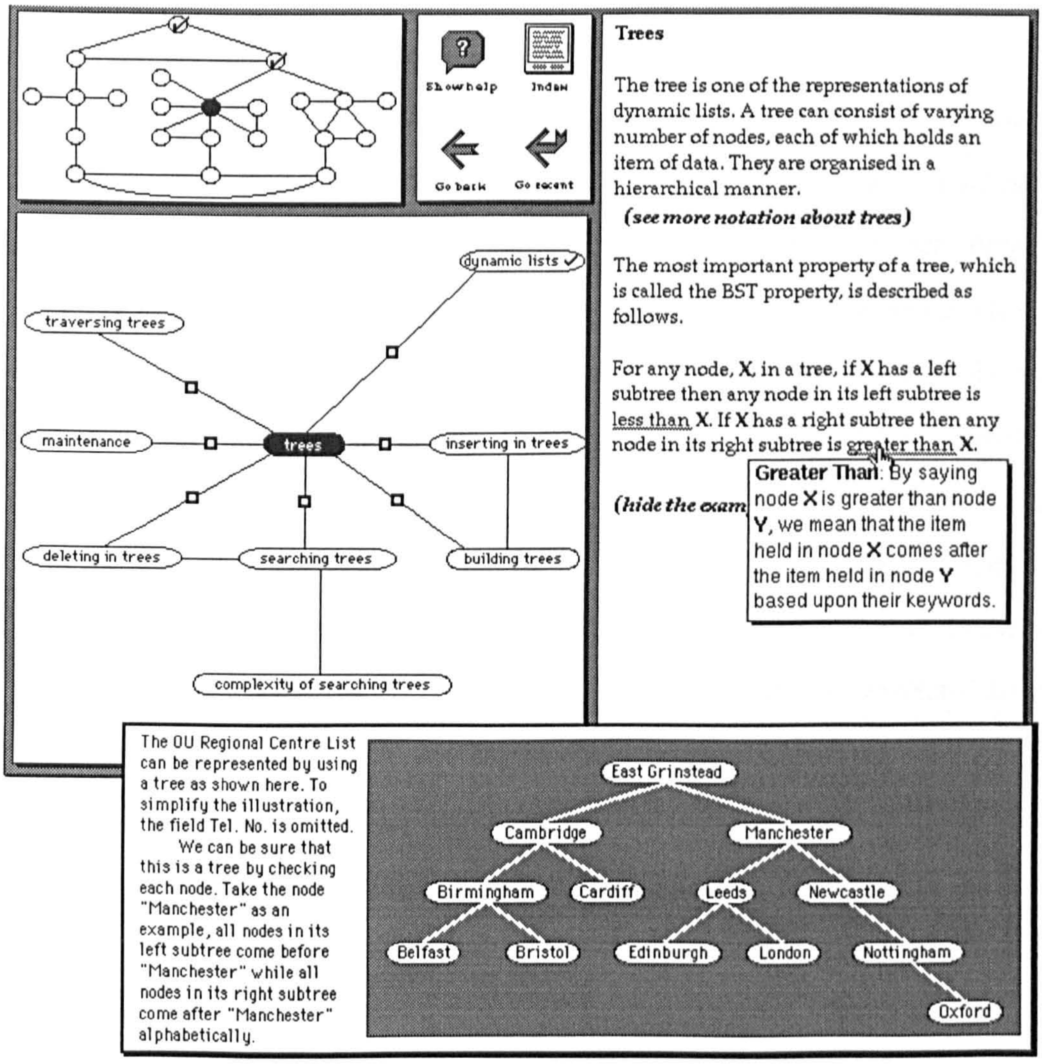

Figure 5.11 An example node of the explicit semantic net hypertext.

• Structure Diagrams

Two levels of structure diagrams are used to assist users to navigate through the hypertext: global diagrams and local diagrams. A global diagram shows the structure of the hypertext, but no semantic information. All primary nodes as well as the associative links connecting them are present in the global diagram, but neither nodes nor links are labelled. Those nodes that have been browsed appear as ticked and the node currently being investigated by the user is distinguished from the others by its black colour. The global diagram is intended to provide users with answers to the following questions at anytime during their navigation: how large is the information space I am dealing with? how interconnected is it? where am I now? how many nodes have I browsed? and how many nodes still remain untouched? The local diagram appears like a "zoom-in" view of the global diagram. In fact, it is not, in the strictest sense, the result of zooming in on the global diagram. The local diagram displays the current node, together with all nodes that connect to it by one or two levels of associative distance, no matter how far they are physically away from the current node in the global diagram. Each node in the local diagram is labelled using the thematic title of the concept represented by the node. As in the global diagram, the browsed nodes and the current node are marked distinctly. Users are expected to rely largely on this diagram for navigation. However, only those nodes which are directly connected to the current one can be approached. This can be fulfilled by clicking those small buttons attached to links (connecting lines) rather than by clicking nodes as in most hypertext systems. The reason for allowing jumping only to the nodes adjacent to the current one is based on the following concerns. Allowing jumping to any node just by clicking on them makes associative links less meaningful so as to violate the knowledge structure imposed by hypertext authors. The use of links as the "click area" rather than nodes themselves is actually the consequence of this design, that is, only those nodes directly connected to the current one are immediately accessible. Of course, the full freedom of jumping in hypertext can be very useful for some kinds of users or at certain learning stages. The system does provide two facilities to do that: the index and the history trail, which will be subsequently discussed.

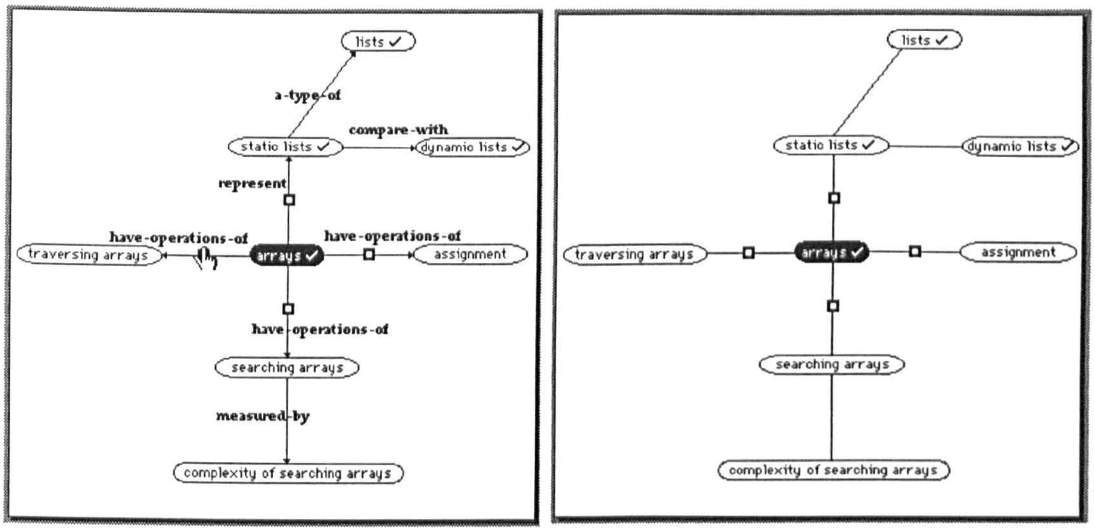

Figure 5.12 The difference in the local diagram between the two experimental versions.

The difference between the two experimental versions of this hypertext only occurs in the local diagram. In the VLTs version, the associative link (the connecting line in its local diagram) is labelled by using the name of the semantic relation between the two nodes it connects, which is usually a verb phrase such as "(are) a-type-of", "include", "compare-with", "(are) represented-by", "have-operations-of", and so forth. The direction of the semantic relation is indicated by putting arrows on linking lines. As stated in Section 3.6.3, a semantic relation has its converse relation, and this can be used to express the same semantic content but in the opposite direction. This raises a problem of which relation should be chosen to express the same semantic content, **R** or its converse relation $\mathbf{R^{-1}}$. The problem is partly settled by making it a rule that the directions of all links should point outward from the current node. The rationale behind this criterion is simply that users normally pay more attention to the current node. However, there exists a situation where the above criterion is not applicable, that is, when the current node together with two other nodes forms a loop. In this case, the relation represented by the link which does not directly connect to the current node is chosen arbitrarily. In contrast, all links in the local diagram of NoVLTs version are simply represented by using plain unlabelled lines. Figure 5.12 demonstrates this difference.

• Index

The Index provides an alphabetical list of thematic titles of all nodes. Users are able to jump to any node directly by selecting its title in the pull-down index menu, as shown in Figure 5.13. The main purpose of this facility is to allow learners to locate a concept more directly by means of its title, particularly when they are reviewing the hypertext.

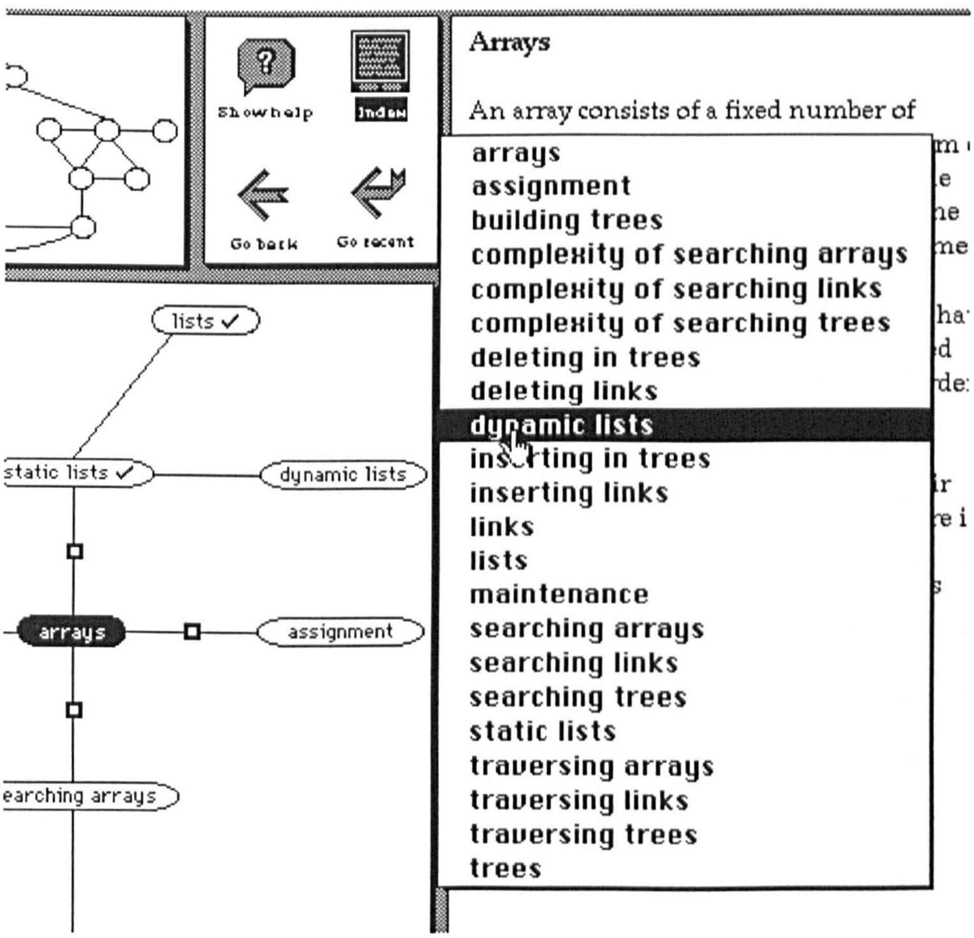

Figure 5.13 An example of the use of Index.

• Backtracking

Backtracking allows users to step back one node at a time through their current session. By means of this facility, the user is able to revisit those nodes in exactly the reverse order in which the user originally visited them. As in most hypertext systems, the backtracking facility in our hypertext is represented by a return arrow icon.

• History Trail

The *go back* backtracking described above only allows one step back whereas the History Trail provides a record of the nodes which have been visited and allows users to return to any previously visited node immediately. HyperCard itself provides a built-in graphical history display called *Recent.* This display contains miniatures, arranged in a grid, of the last 42 nodes visited. The idea behind this type of display is to take advantage of the user's visual memory. However, this display does not contain a strictly historical trace since if a node is visited more than once, it is not added to the display. An out-of-context history list provided by *Recent* is considerably harder to interpret than a path-following history record since it removes information about the transitions between nodes (Neilsen, 1990b). On the other hand, the advantage of displaying miniatures becomes diminished because of the trivial difference in appearance among the cards in our hypertext. These are reasons underlying our decision not to use the HyperCard built-in *Recent.* Instead, the history trail facility used in our hypertext includes the titles of the last thirty nodes the user has visited in the sequential order of the visiting. Users can jump to any visited node simply by selecting its title in the pull-down history trail menu, as illustrated in Figure 5.14.

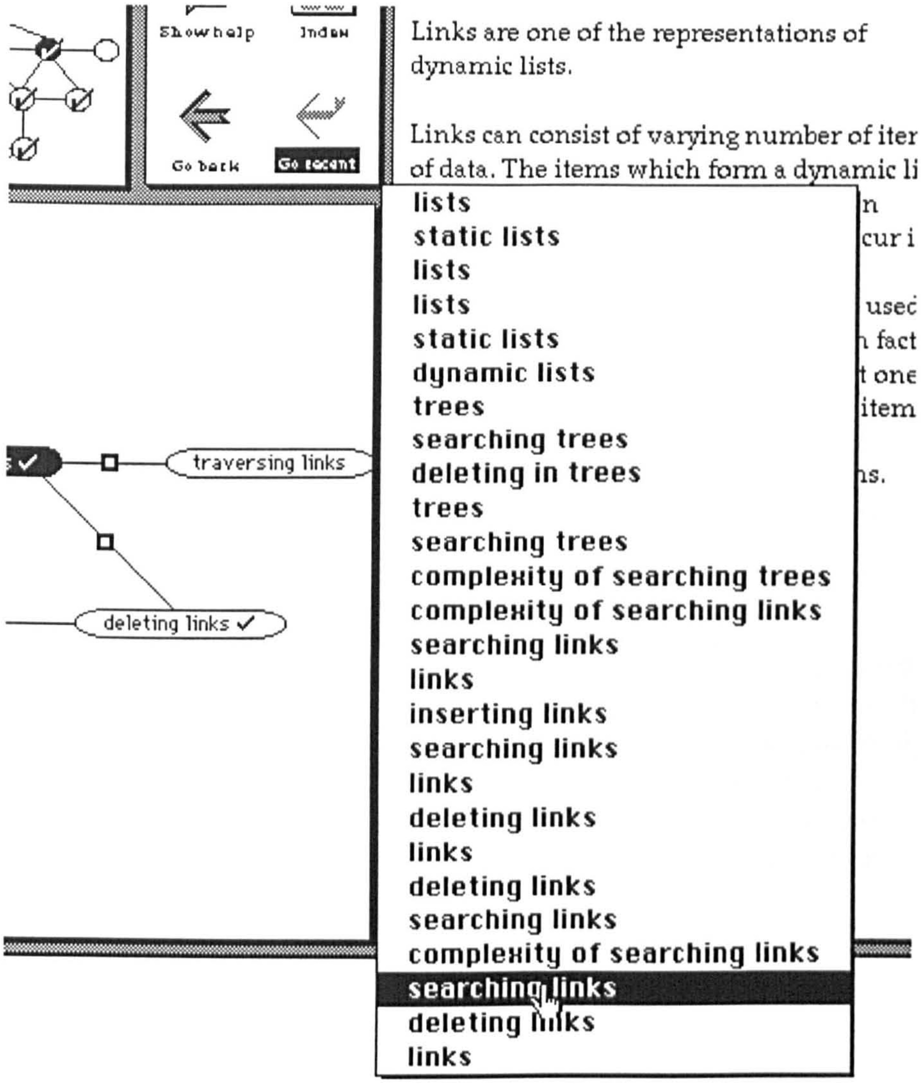

Figure 5.14 An example of the use of History Trail.

• Balloon Help

Balloon Help provides the information on the use of navigational facilities in context. To turn on Balloon Help, the user clicks on the balloon icon. After that, the icon remains highlighted to indicate the active status of Balloon Help. A small explanatory comment in a cartoon-like balloon will appear as the mouse is dragged to any object in a card (see Figure 5.15). Importantly, while Balloon Help is active, the user still has full control over the system, in spite of balloons appearing all over the screen. To prevent these balloons from getting in the way, Balloon Help can be turned off at any time simply by clicking on the balloon icon again.

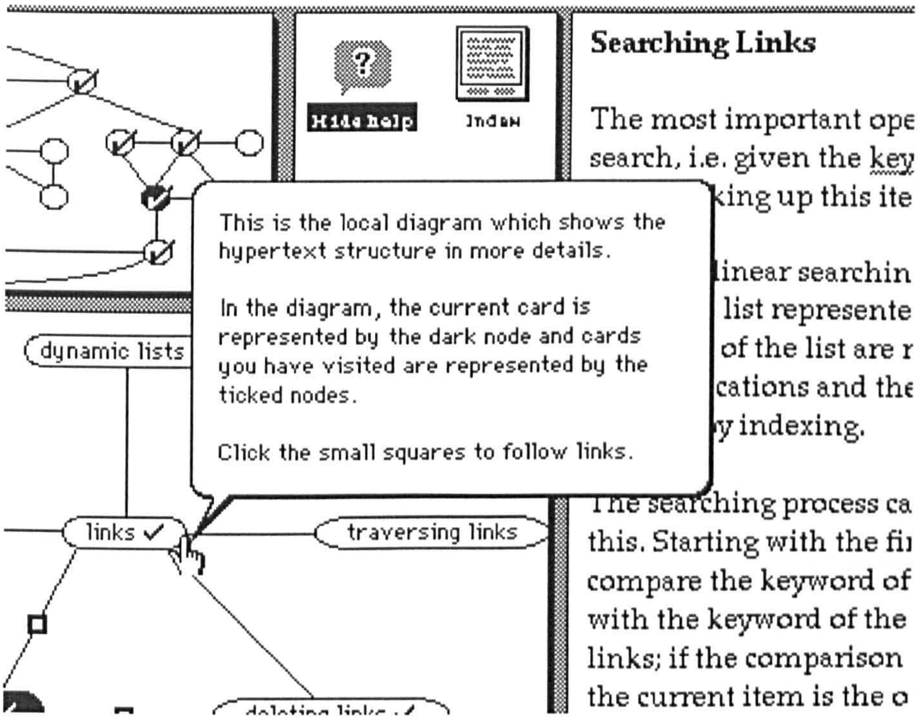

Figure 5.15 An example of the use of Balloon Help.

5.5.2 System Implementation

This system was also implemented on an Apple Macintosh with HyperCard 2.1 as the authoring tool. It comprises twenty-four 640×480 cards and approximately one hundred and fifty links, three thousand and five hundred words, and a dozen graphics and animations. The whole hypertext system, including a Hypertext stack, 12 PICT files, and 3 QuickTime files, takes about 400Kbytes on hard disk. The system has good response time. The following paragraphs briefly describe the implementation of each interface element.

• Structure Diagrams

Both the global and the local structure diagrams in the system have been generated manually. It is possible to let the computer do the job as in some hypertext systems like NodeCards (Halasz, Moran, & Trigg, 1987) and StackMaker (Hutchings, Carr, & Hall, 1992). In the hypertext system we used, the global diagram shows the complete hypertext structure immovably in a small window and the local diagram displays also immovably the current node as well as all nodes, connected to it by one or two levels of associative distance, with the titles of these nodes (and even the names of links in the VLTs version) in a fixed window. The scale of the current knowledge domain and its more simply interrelated structure make it possible to implement this design. Such a design could become impractical when the scale and complexity of the hypertext structure increase. An alternative designs in this case might use the fisheye view model (Furnas, 1986) together with the link filtering technique (Parunak, 1991; Tomek & Maurer 1992). We will discuss this issue more fully as part of plans for further work in the final chapter of this thesis.

• Index and History Trail

Basic HyperTalk does not provide an easy way to create a pull-down menu with a fixed number of items, which was necessary to implement the design of our Index. It is almost impossible to realise a pull-down menu for our History Trail just using basic HyperTalk because the number of items in the History Trail menu increases while the hypertext is browsed by users. An XFCN named *HPopupMenu* was added to the basic HyperCard functionality for the implementation of our Index and History Trail menus. This XFCN can be used to create a pull-down menu with either a fixed or changeable number of items. It also allows building up a walk-through (or cascading) menu.

• Hotpoint

The *hotpoint* was built upon the "active text" features introduced in HyperCard2.0. Active text is a text which is capable of responding to actions by the reader, i.e., clicking on the text with the mouse. Three functions (*clickText, clickChunk*, and *clickLine*) and a new text style *group* are adopted to facilitate the construction of active text in fields. Active text does not suffer from the drawbacks of buttons pasted over text; the text can be edited or scrolled without undesirable results. The active text can be automatically designated (with a grey line underneath the grouped text) by including the command *show group* in the system message handler *openStack.*

In the development of our hypertext, locating and grouping the *hotpoint*, and attaching it with its footnote-like information were all fulfilled manually. In fact, the stack can be programmed to undertake this job. First of all, one would store all selected phrases as well as their corresponding footnotes in a glossary field. Then, one would build up a script for an "action" button, which checks every phrase in each text field against the phrases stored in the glossary, groups every matched phrase in the text field, and attaches it with its footnote information. The reason why we implemented the *hotpoint* referential links manually was to produce an experimental system in a short period of time, which would satisfactorily fulfil needs of the research described in this thesis.

• Floating Windows

Although basic HyperCard does not support multiple windows, we incorporate floating windows in our stack by means of externals. The main reason for this is to enlarge the capacity and enrich the format of nodes. There are two types of floating windows contained in the stack. The first type is the QuickTime animation window that is integrated into the stack through the *Movie* XCMD as described earlier in this chapter. The second type is the graphical window that is integrated into the stack through the *Picture* XCMD. *Picture* can be used to display colour or grey-scale pictures in an external window. The picture can be stored in a PICT/MacPaint file, clipboard, and the stack resource fork.

• Balloon Help

This facility is realised by using the *Balloon* XCMD that is a simple implementation of System7 Balloon Help for HyperCard stacks. *Balloon* can be used to switch on/off the Balloon Help mechanism of System7 and to add help information to buttons and fields in the HyperCard stack in the standard balloon format.

5.6 Summary

In this chapter, we have described the design and implementation of the experimental hypertext systems used in the study: the embedded semantic net hypertext and the explicit semantic net hypertext. Each system has two versions. One is referred to as the VLTs version where the semantic relation between nodes is visualised, the other is referred to as the NoVLTs version where such relations are invisible. Now we are in the position to address the kernel issue of the research – testing our hypothesis that the visualisation of semantic relations between nodes might improve learning in hypertext learning systems.

Chapter 6 A Set of Empirical Studies

6.1 Introduction

The main task of the research described in this thesis is to test the hypothesis that the visualisation of semantic relations between nodes might improve learning in hypertext learning systems. In this chapter, we report a set of three empirical studies which were designed to fulfil the task. The methodologies adopted, results obtained, and their implications will be described in detail.

The studies started with an easily-built hypertext system which as defined in Chapter 3 and 5 belongs to the category of embedded semantic net hypertext. The positive result from this first study inspired us to test our hypothesis further with a hypertext system which falls into another category - explicit semantic net hypertext. The two kinds of hypertext systems differ from each other in whether or not a graphical browser is provided to users for navigation. Therefore, the extent to which semantic relations between nodes can be visualised varies in the two different categories of hypertext.

Human learning is situated in the sense that the way people learn, and the cognitive abilities they use, depend on the nature of the learning situation (Hutchings, et al., 1992). One of the most important elements of the learning situation is learning tasks. Hypertext-based learning environments are regarded as more suitable for exploratory learning applications since hypertext shares many of the characteristics that are integral to exploratory learning (Heller, 1990). However, the learning task used in the first two of our studies was goal-oriented, which involves different cognitive processing than the exploratory learning. Therefore, a third study was decided to focus on the exploratory learning.

Evaluation becomes problematic when the objects of evaluation are complex, novel, or abstract. The evaluation effort in the studies described here involved a learning system based on a new technology, i.e., hypertext, and an abstract objective, i.e., the effect of visualisation of semantic relations on learning. To tackle the difficulty a multi-faceted approach to the evaluation was employed over the three studies. By being multi-faceted, it means that the approach comprises various components, each contributing in a different way to the evaluation effort. The components form two dimensions of the approach. One is measures which include learning outcomes, learning processes, and learner satisfaction. The other is data collection methods which include interviews, questionnaires, user usage logs, teach-back tests, think-aloud protocols, and video-tapes.

6.2 Study One

The purpose of this study is to investigate the effects of the visualisation of semantic relations between nodes on goal-oriented learning in an embedded semantic net hypertext with the hypothesis that students viewing link-types could learn better than those viewing no link-types.

6.2.1 Method

Participants

Twenty adult volunteer subjects, who were staff or students of the Open University, took part in the study. They were randomly divided into two equal-sized groups without regard to gender, namely, an experimental group and a control group.

Learning Materials

An embedded semantic net hypertext, whose topic was the search tree of data structures in computing, was used as the learning material. Two versions of the hypertext were adopted for the two different experimental conditions in the study. They were referred to as VLTs (Visible Link-Types) and NoVLTs (No Visible Link-Types). The differences between the two versions lay in the ways associative and referential links were denoted. In the VLTs version, the associative link was labelled explicitly by using the name of the semantic relation between the two nodes it connects, and the referential link was attached with a small palette which contained the semantic relationship between the reference and its referent and was visible only when the link was pointed to by the user. In the NoVLTs version, all associative links were labelled as *related content*, and no information was attached with the referential link. To see the detail, refer to the section of "An Embedded Semantic Net Hypertext System" in Chapter 5.

Instruments

Three testing instruments were used in this study (see Appendix A). The first was a printed self-assessment form which was designed to investigate the subject's prior knowledge of using a Macintosh machine, hypertext systems, and data structures in computing. The second was an electronic questionnaire created in HyperCard. It consisted of ten multiple-choice questions on the learning materials, each of which was assigned one point. The third was a printed questionnaire which was designed to determine the level of user satisfaction with the hypertext.

Procedure

The procedure consisted of three steps. In the first step the subject was asked to do a pre-test, which consisted of two tasks: filling in the printed self-assessment form and completing the electronic questionnaire. Before starting the second task, subjects were told that the same multiple-choice questionnaire would be used in the post-test. In the next step, the subjects were exposed to a specific version of the experimental hypertext system according to which group they had been randomly assigned. The VLTs version was used in the experimental group and the NoVLTs version was used in the control group. For ease of reference, the experimental group will be referred to as the VLTs group and the control group as the NoVLTs group. Before starting to work through the hypertext, subjects received a brief introduction to the use of the system and were instructed to work at their own pace without being given any time limit. When the subject felt browsing time sufficient, she/he then went on to complete the post-test. The post-test also comprised two tasks: answering the same electronic questionnaire used in the pre-test and completing the satisfaction questionnaire.

Subjects' scores on the electronic questionnaire for both pre- and post-test were recorded automatically by the questionnaire stack. A set of monitoring scripts embedded in the experimental hypertext recorded subjects' behaviour, including the navigational path, the total time spent on browsing, the time allotted to each card, and the activation of associative and referential links. This data was intended for subsequent analysis of learning processes.

6.2.2 Results

Learning Outcomes

Table 6.1 presents the mean correct percentages and standard deviations of post-test scores for both the experimental group (VLTs) and the control group (NoVLTs). An examination of Table 6.1 revealed that mean post-test scores of subjects in the VLTs group were ordered higher than mean scores of subjects in the NoVLTs group. A one-factor ANOVA test was performed on the post-test scores to examine the reliability of this observation (see Figure B.1 in Appendix B). The test yielded $F(1,18)=3.80$, with significance level $p=.07$. However, a further exploration of the data regarding learning outcomes collected from the study led to applying a more precise statistical method. Even though the subjects were assigned at random to the groups, an initial difference in prior knowledge scores (equally weighted sum of self-assessment and pre-test scores) in favour of the control group (NoVLTs) was observed (see Table B.1.1 and B.1.2 in Appendix B). Moreover, a Pearson product-moment correlation test showed that subjects' prior knowledge scores correlated positively and consistently with their performance in the post-test across both groups ($r=.25$, $r=.48$), i.e., that subjects with higher prior knowledge scores did better in the post-test than subjects with lower prior knowledge scores (see Table B.2.1 and B.2.2 in Appendix B). A higher reliability of the observation (i.e. subjects in the VLTs group achieved more than subjects in the NoVLTs group in the post-test) or a lower significance level, in other words, was expected after the mean post-test scores of both groups had been adjusted or controlled for prior knowledge scores. Therefore, it was decided to perform an analysis of covariance on the mean post-test scores, where the link group (VLTs vs. NoVLTs) was the between-group factor, and prior knowledge scores were utilised as the covariate (see Figure B.2 in Appendix B). This more precise ANCOVA test yielded $F(1,17)=4.35$, the significant level $p=.05$, showing that subjects in the VLTs group did indeed outperform subjects in the NoVLTs group in the post-test.

Table 6.1 Means (standard deviations) of percentage correct on post-test scores as a function of link group.

Link group	Post-test
VLTs (n=10)	78 (13.98)
NoVLTs (n=10)	61 (23.78)

Compared to Table 6.1, a column chart as Figure 6.1 presents the difference of post-test scores between the two groups more clearly.

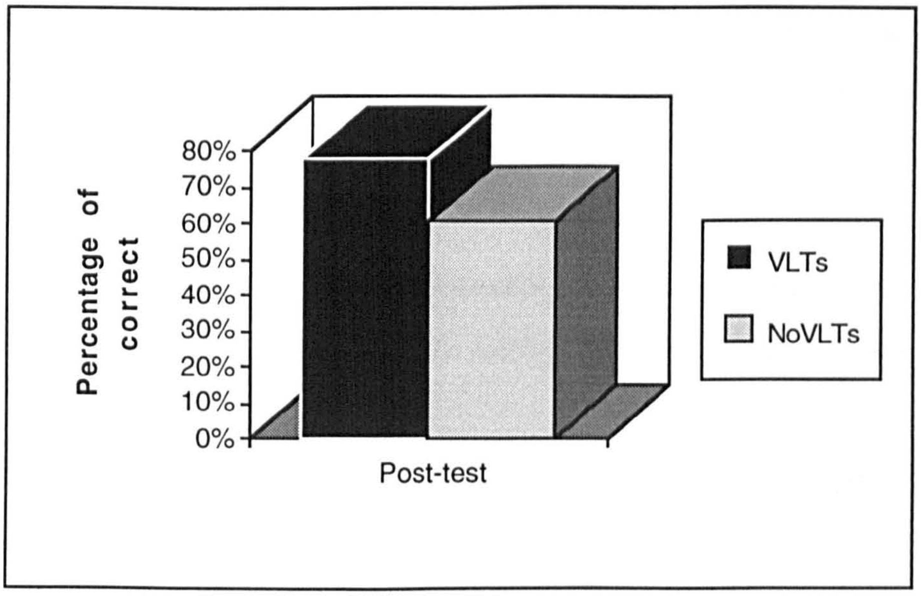

Figure 6.1 Means of percentage correct on post-test scores for the two experimental groups.

Learning Processes

Learning processes were investigated in this study through two factors: a set of performance indicators and learner navigation patterns. The data from which the navigation patterns and performance indicators were built was collected by means of monitoring scripts incorporated in the experimental hypertext systems.

Table 6.2 shows a set of performance indicators, including the browsing time, the number of cards browsed, the sum of different cards browsed, the number of times associative links were activated, and the number of times referential links were followed (see Table B.3.1 and B.3.2 in Appendix B for details). The following two points are revealed in the data included in the table.

Firstly, subjects in the VLTs group explored the system more extensively than their counterparts in the NoVLTs group. The evidence was that on average subjects in the VLTs group spent a longer time on the program, visited slightly more different nodes, and browsed a larger number of cards than subjects in the NoVLTs group. In order to measure this more precisely, we used two parameters: completion rate C and repetition rate R. They were defined respectively as:

$$C = \langle \textit{number of different cards browsed} \rangle / \langle \textit{total number of cards} \rangle \times 100\%$$

$$R = \langle \textit{number of cards browsed} \rangle / \langle \textit{number of different cards browsed} \rangle$$

The indication that subjects in the VLTs group explored the hypertext more extensively than subjects in the NoVLTs group was that both the completion rate and repetition rate of VLTs group were greater than those of NoVLTs group ($C_{VLTs}=81.5\%$, $C_{NoVLTs}=78.2\%$; $R_{VLTs}=3.2$, $R_{NoVLTs}=3.1$).

Secondly, subjects in the VLTs group used less associative links (*25 times*) than subjects in the NoVLTs group (*32 times*). In contrast, subjects in the NoVLTs group used less organisational links than subjects in the VLTs group. Although this was not shown directly in Table 6.2 because the activation of organisational links was not captured by the embedded monitoring scripts, it could be worked out simply by taking away the times of activating associative links and referential links from the number of cards browsed. This was because the number of cards browsed was equal to the number of links activated in a session and also because there were only three kinds of links in total in the hypertext. Therefore, the mean times of activating organisational links by subjects in the NoVLTs group and the VLTs group were respectively: forty times (*82-32-10=40*) and fifty-four times (*89-25-10=54).*

Table 6.2 A set of performance indicators: means (standard deviations) of data in relation to subjects' actions.

Link group	Total browsing time (min)	Total cards browsed	Different cards browsed	Associative links activated	Referential links activated
VLTs	22.1 (5.5)	89.3 (24.9)	27.7 (3.2)	25.1 (10.4)	10.2 (7.0)
NoVLTs	21.5 (6.5)	81.6 (29.6)	26.6 (3.9)	31.8 (16.7)	9.6 (6.9)

The basic method of analysing learner navigation patterns was to compare and classify subjects' navigational paths captured by the experimental hypertext system. In fact, the comparison and classification were not made upon the originally captured data, but upon its graphical representations instead, which were similar to directed graphs (see Figure 4.4 in Chapter 4) in graph theory. It was discovered that almost all subjects developed the same systematic method to navigate the hypertext after a brief period of practising. The method could be loosely viewed as similar to Depth-first-search introduced in computer data structures. Apart from one subject of the VLTs group whose navigational data was lost accidentally, only one subject was found who applied a combined navigational strategy. He first browsed the hypertext using the Depth-first-search-like approach, then went through it again by following the linear order in which cards were physically stored. He was able to do so because he was familiar with HyperCard in which the hypertext was created, as he told the experiment administrator later on. Despite the same navigational strategy used, two different navigation patterns were recognised. One was the strict hierarchical, the other was the extended hierarchical. In the former, subjects went up to a node in the structure by reversing the path which previously led them from that node to the current one, so that the graphical representation of the strict hierarchical pattern looked like a tree. In the latter, subjects sometimes followed a short-cut, facilitated by some organisational links, to go back to a node previously visited so that the graphical representation of the extended hierarchical pattern was no longer a tree. It was found that only one out of nine in the VLTs group followed a strict hierarchical pattern whereas three out of ten in the NoVLTs group did so. Overall in both groups, though, most subjects followed an extended hierarchical pattern.

Learner Satisfaction

The printed satisfaction questionnaire was used as part of the post-test to probe subjects' subjective satisfaction with the use of the hypertext system and their attitude towards the design related to visualisation of link-types. It consisted of four scaled questions as well as an open question, as listed below:

Q1 How did you enjoy using this hypertext system?

Q2 How easy did you find it to browse through this hypertext system?

Q3 Did you find the labels on the buttons helpful in finding the information you wanted?

Q4 What do you think of the way a *hotpoint* (a textual string with an underline) was represented in the hypertext system?

Q5 Please write any other comments you may wish to make about the hypertext system.

Table 6.3 demonstrates subjects' responses to the four scale questions. Subjects' answers to the open question largely focused on their dissatisfactions and suggestions for improving the system. They are summarised into the following five points.

(1) Lack of a complete overview of the net structure was a hindrance; I wanted an overview diagram.

(2) I sometimes forgot which parts of the system I had already explored; perhaps there could be a dynamic "where you've already been" page (presumably with a map of the hyperspace).

(3) The visual demonstrations of examples were very helpful, but I'd rather be able to manipulate the examples by myself to test my understanding than watch the system doing it.

(4) Information contained in most cards was too dense.

(5) Dislike of the *related content* button was one of the main complaints from subjects in the NoVLTs group.

Table 6.3 Subjects' responses to the scaled questions.

Q1	Very much	Fairly	Not very	Not at all
VLTs	4	6	0	0
NoVLTs	3	5	2	0

Q2	Very easy	Easy	Average	Difficult	Very difficult
VLTs	5	3	2	0	0
NoVLTs	0	4	5	1	0

Q3	Very helpful	Helpful	Not very helpful	Very difficult
VLTs	2	8	0	0
NoVLTs	0	7	3	0

Q4	Very good	Good	Average	Poor	Very poor
VLTs	4	5	1	0	0
NoVLTs	1	2	5	1	0

6.2.3 Implications and Discussion

The results of this study suggest that explicitly labelling links with semantic relations has a positive influence on goal-oriented learning in an embedded semantic net hypertext system. First of all, the result of learning outcomes showed that subjects in the VLTs group did indeed outperform subjects in the NoVLTs group in the post-test. Secondly, subjects' responses to the satisfaction questionnaire also indicated that subjects in the VLTs group were more satisfied than subjects in the NoVLTs group with their assigned hypertext systems. The difference of degree of satisfaction between two groups could be described more specifically as this. Half the subjects from the VLTs group but none from the NoVLTs found it very easy to browse through the hypertext. To the question "Did you find the labels on the buttons helpful in finding the information you wanted?" in the VLTs group, two answered "very helpful" and eight said "helpful"; while in the NoVLTs group, none answered "very helpful," seven said "helpful," and three said "not very helpful." Almost all subjects from the VLTs group felt that the way the *hotpoint* was represented was very good or good, while most participants from the NoVLTs group thought the way of representing the *hotpoint* in their version was just average.

Nevertheless, conclusions relating to learning process results were rather ambiguous. Let us look into this issue more closely. Subjects in the VLTs group explored the system more extensively than subjects in the NoVLTs group, perhaps because subjects in the VLTs group were enjoying working on the hypertext more than their counterparts in the NoVLTs group. The fact that the associative link was activated fewer times by subjects in the VLTs group than by subjects in the NoVLTs group might suggest that subjects in the VLTs group, who were able to view semantic relations between nodes, were probably more confident in finding the information they wanted than their counterparts in the NoVLTs group. The fact that the same navigational strategy was adopted by nearly all subjects without regard to the hypertext version used could be explained by the belief that the availability of navigational strategies in hypertext depends on the topology of the hypertext (Parunak, 1989, 1991). Since the two hypertext versions used for the study had the same hierarchical topology, an identical navigational strategy was expected to be developed by the all subjects according to the above assumption. Besides the topology of hypertext, there might be two other factors which contributed to the particular strategy, i.e., Depth-first-search, used by our subjects. One was that the navigational means provided in the hypertext system was so plain that it was not very easy to jump from one topic to another when being within a topic. The other was that most people tend to explore knowledge in a vertical manner, i.e., depth first. The reason why a larger proportion of subjects in the VLTs group took the extended hierarchical navigation pattern than in the NoVLTs group (or smaller proportion of subjects in the VLTs group took the strict hierarchical navigation pattern than in the NoVLTs), is not clear.

As observed when we were choosing a statistical method to analyse learning outcomes, it was evident that subjects' individual differences in prior knowledge played a mediational role in differentially designed treatments. Subjects' prior knowledge was related positively and highly to their performance in the post-test in both treatments ($r=.25$, $r=.48$) (see Table B.2.1 and B.2.2 in Appendix B).

In this study, we also examined more closely the effect of the interaction between the type of hypertext versions used and subjects' prior knowledge scores on their improvement scores – differences between pre-test and post-test scores on the electronic questionnaire. To do that, in addition to the hypertext version used, a second independent variable was introduced, which was, the individual prior knowledge scores. Subjects were split into two types by the median (*0.24*) of all subjects' prior knowledge scores. The subjects whose scores were higher than, or equal to, the median were recognised as the learners with higher individual prior knowledge, whereas the subjects whose scores were lower than the median were considered as the learners with lower individual prior knowledge. Thus, each subject fell into one and only one of four sub-groups: using VLTs and with higher prior knowledge, using VLTs and with lower prior knowledge, using NoVLTs and with higher prior knowledge, and using NoVLTs and with lower prior knowledge (see Table B.4.1 and B.4.2 in Appendix B for details of such a classification). The mean improvement scores for the four sub-groups could be presented in a 2×2 table as shown in Table 6.4. It was found that in the VLTs treatment subjects with lower prior knowledge scores were improved more than those with higher prior knowledge scores. Conversely in the NoVLTs treatment the subjects with lower prior knowledge scores were improved less than those with higher prior knowledge scores. These could be more clearly illustrated by Figure 6.2. It seemed to suggest that the learners with lower prior knowledge could benefit more from the visible link-types (i.e., semantic relations between nodes) than the learners with higher prior knowledge. However, a two-factor ANOVA test showed that the effect of interaction between the type of hypertext versions used and subjects' prior knowledge scores on subjects' improvement scores was not significant (see Figure B.3 in Appendix B).

Table 6.4 Means of improvement scores as a function of hypertext versions and prior knowledge.

Link group	High prior knowledge	Low prior knowledge
VLTs	5.6 (n=5)	6.0 (n=5)
NoVLTs	4.4 (n=5)	3.8 (n=5)

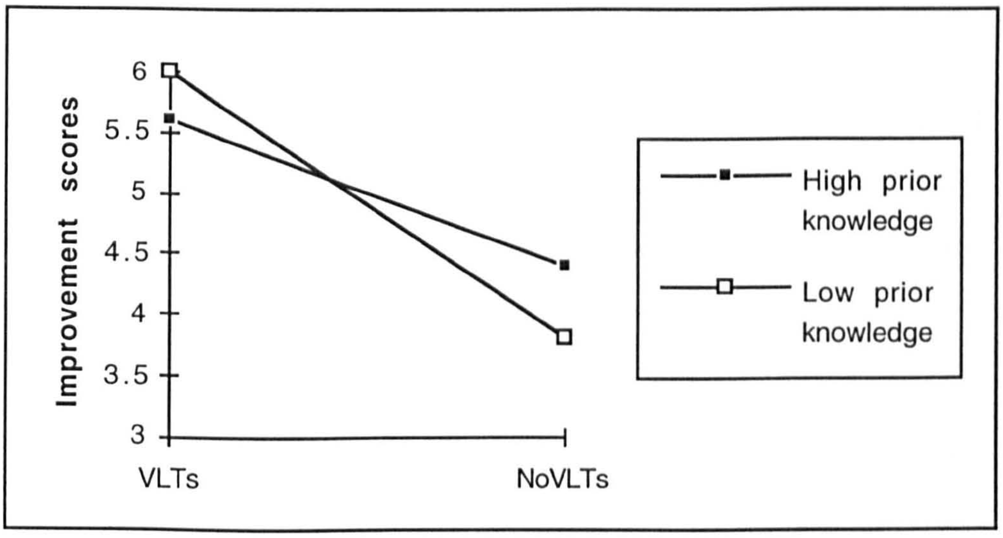

Figure 6.2 Effects of interaction between hypertext versions used and prior knowledge on improvement scores.

6.3 Study Two

Study One has suggested that the proposed approach has a positive effect on goal-oriented learning in an embedded semantic net hypertext system. The purpose of Study Two was to examine if the approach of visualising semantic relations between nodes still held good for goal-oriented learning in the context of the explicit semantic net hypertext system. As in the first study, this examination was carried out by comparing the learning gains, learning processes, and learner satisfaction of the two experimental conditions. In evaluating learning outcomes, however, we looked particularly at two kinds of outcomes, namely, structural knowledge acquisition and specific nodal information gains.

6.3.1 Method

Participants

Twenty seven paid subjects, who were first-year undergraduate students at the School of Computing & Mathematical Sciences, De Montfort University, Milton Keynes, took part in the study. They were randomly divided into an experimental group and a control group without regard to gender. The former consisted of fourteen subjects and the latter thirteen.

Learning Materials

An explicit semantic net hypertext based on lists of data structures in computing was used as the learning material. Two versions of the hypertext were adapted for the two different experimental conditions in the study. They were referred to as VLTs (Visible Link-Types) and NoVLTs (No Visible Link-Types). The differences between the two experimental versions of this hypertext occurred in the local diagram. In the

VLTs version, the associative link (the connecting line in its local diagram) was labelled by using the name of the semantic relation between the two nodes it connects, which was usually a verb phrase such as *(are) a-type-of*, *include*, *compare-with*, *(are) represented-by*, *have-operations-of*, and so forth. In contrast, all links in the local diagram of the NoVLTs version were simply represented by using plain unlabelled lines. To see this in detail, refer to the section of "An Explicit Semantic Net Hypertext System" in Chapter 5.

Instruments

Three testing instruments (see Appendix C) were used in this study. The first was a printed self-assessment form which was designed to investigate the subject's prior knowledge of using a Macintosh computer, hypertext systems, and data structures in computing. The second was a printed learning assessment questionnaire to investigate subjects' structural knowledge and nodal information gains. It consisted of two parts, each containing ten multiple-choice questions. Part One was designed to determine subjects' structural knowledge acquisition. Structural knowledge in this context is the knowledge of how concepts within a domain are interrelated (Jonassen & Wang, 1993). In hypertext systems which, as indicated in Chapter 3, can be conceived of as knowledge representations, the structural knowledge is largely conveyed by means of such facilities as links, graphical browsers, and content tables. More specifically, two kinds of questions were included in Part One in order to measure different aspects of structural knowledge. The first five questions required subjects to identify the correct semantic relationship between two or more concepts, which was conveyed by the hypertext structure. The next five questions required subjects to work out the relationship implied in a given pair of concepts by choosing one from three pairs of concepts, which best expressed a relationship similar to that expressed in the original pair. The second part of the learning assessment questionnaire focused on examining subjects' gains of nodal information – basic elements of information held within individual nodes in the hypertext. Finally, a satisfaction questionnaire and an accompanying interview were designed to elicit each subject's view on the usability of the system.

Procedure

As in Study One, the procedure of this study was composed of three phases. In the first phase, subjects were asked to do a pre-test, which included filling in the self-assessment form and completing the learning assessment questionnaire. Before beginning the second task, subjects were informed that the same questionnaire would be used to assess their learning outcomes in the subsequent post-test. In the next phase, subjects were exposed to a specific version of the experimental hypertext system according to which group they had been randomly assigned. The VLTs version was used in the experimental group and the NoVLTs version was used in the control group. The experimental group will be referred to as the VLTs group and the control group as the NoVLTs group. Before starting to work through the hypertext, subjects received a brief introduction to the use of the system and were instructed to work at their own pace without being given a time limit. Subjects were also requested to verbalise their thoughts as far as possible during their interaction with the hypertext. As soon as they felt their interaction was complete, subjects were given a post-test. The post-test included answering the learning assessment questionnaire already used in the pre-test, completing the satisfaction questionnaire, and being interviewed by the experiment administrator. The questions asked in interviews were based on the satisfaction questionnaire. Subjects were requested to express their impressions about use of the systems.

In an attempt to understand subjects' interaction with the system better, as well as a set of monitoring scripts embedded in the hypertext, a video camera was also used mainly for the purpose of recording think-aloud protocols together with corresponding scenes. The camera was placed in a fixed position to the screen with no operator present during study-time. Since the hypertext used in this study provided several different modes of navigation, the monitoring scripts recorded not only navigational paths but also the way of jumping. The final interview with subjects was tape-recorded.

6.3.2 Results

Learning Outcomes

Table 6.5 presents the mean correct percentages and standard deviations of each part of the post-test scores (i.e. structural knowledge and specific nodal information) for both the experimental group (VLTs) and the control group (NoVLTs). An examination of Table 6.5 reveals that the mean scores of the NoVLTs group were ordered higher than mean scores of the VLTs group regarding structural knowledge acquisition whereas the situation in the specific nodal information gains was just the opposite.

Pearson product-moment correlation was computed to examine the relationship between each part of the post-test scores and prior knowledge scores (equally weighted sum of self-assessment and pre-test scores). The results revealed that subjects' prior knowledge scores correlated positively and significantly with their performance in each part of the post-test across both groups ($r=.71$, $r=.87$; $r=.62$, $r=.69$) (see Table D.2.1 and D.2.2 in Appendix D).

It could be predicted that the difference of mean scores of the first part (i.e. structural knowledge) between two groups would be enlarged whereas the difference of mean scores of the second part (i.e. specific nodal information) would be diminished after the scores had been adjusted for prior knowledge scores. This is because the difference in prior knowledge scores initially existing between two groups was in favour of the experimental group (VLTs) (see Table D.1.1 and D.1.2 in Appendix D). Therefore, ANCOVA was chosen to perform separately on the mean scores of each part of the post-test, where the link group (VLTs vs. NoVLTs) was adopted as the between-group factor and prior knowledge scores were used as the covariate. The ANCOVA test yielded $F(1, 24)=3.40, p=.08$ for the first part and $F(1,24)=.80, p=.38$ for the second part respectively (see Figure D.1 in Appendix D). This indicates that even though subjects in the NoVLTs group did better than subjects in the VLTs group in understanding structural knowledge and subjects in the VLTs group did better than subjects in the NoVLTs group in acquiring nodal information, the differences were not, however, significant statistically.

Table 6.5 Means (standard deviations) of percentage correct on post-test scores as a function of link group.

Link group	Structural	Nodal
VLTs (n=14)	47.14 (18.99)	71.43 (24.13)
NoVLTs (n=13)	56.15 (18.50)	64.62 (22.95)

This difference in post-test scores can be seen more clearly in chart form (Figure 6.3).

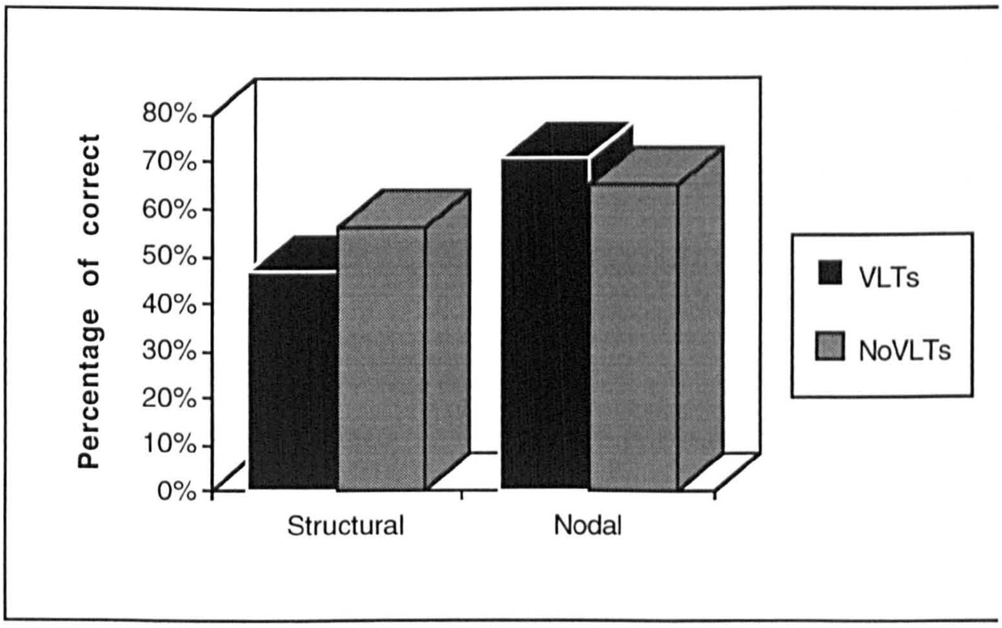

Figure 6.3 Means of percentage correct on post-test scores for the two experimental groups.

Learning Processes

Learning processes were explored in more depth in this study than in the previous one. Besides a set of performance indicators and learner navigation patterns, the data collected from the think-aloud and interview were used to help us interpret subjects' interaction with the systems.

Table 6.6 A set of performance indicators: means (standard deviations) of data in relation to subjects' actions.

Link group	Total browsing time (min)	Total cards browsed	Different cards browsed	"Diagram" mode	"Index" mode	"Back" mode	"Recent" mode
VLTs	37.0 (10.1)	45.6 (15.0)	22.0 (0.0)	31.7 (16.0)	8.1 (12.9)	3.9 (8.5)	3.9 (8.5)
NoVLTs	35.2 (11.2)	45.6 (15.6)	21.8 (0.8)	38.5 (13.6)	3.8 (4.3)	2.0 (3.7)	2.0 (3.7)

Table 6.6 shows a set of performance indicators, including the browsing time, the number of cards browsed, the sum of different cards browsed, the times of using different jumping modes (see Table D.3.1 and D.3.2 in Appendix D for details). Unlike the hypertext system used in Study One, the system used in this study provided four possible ways of jumping from one node to another. These were jumping through the local structure diagram, jumping through the index, jumping through backtracking, and jumping through the history trail (see the section of "An Explicit Semantic Net Hypertext System" in Chapter 5). An examination of Table 6.6 revealed that the two groups were nearly the same in their efforts to explore the system, spending nearly the same length of time on the program and browsing the same number of cards. It was also revealed that the diagram jumping mode was used significantly more than other modes for both groups but the two groups varied in using different jumping modes. To identify more explicitly the difference between two groups in use of jumping modes, the average percentages of jumping by different

modes to total jumping were worked out as shown in Table 6.7 as well as its 3-D column chart (Figure 6.4).

Table 6.7 Mean percentages of jumping through different modes to total jumping.

Link group	"Diagram" mode	"Index" mode	"Back" mode	"Recent" mode
VLTs	66.6	17.0	8.2	8.2
NoVLTs	83.2	8.2	4.3	4.3

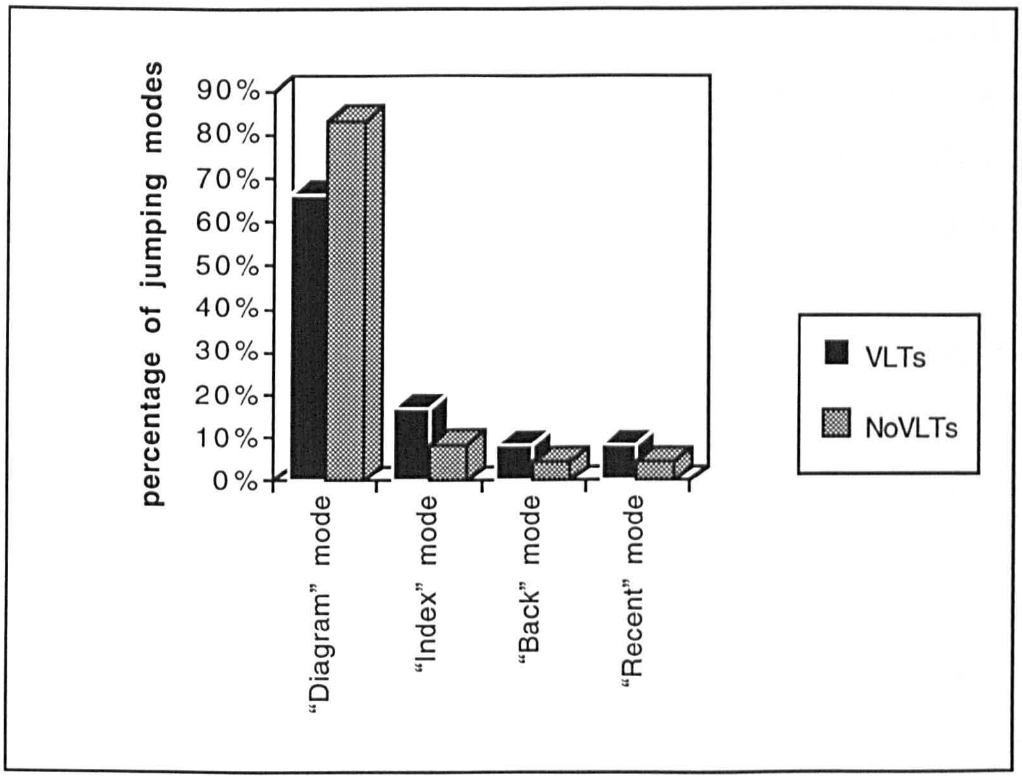

Figure 6.4 Differences between two groups in the use of jumping modes.

It was clear that subjects in the NoVLTs group applied the diagram mode more frequently than subjects in VLTs group whereas subjects in the VLTs group used each of the other modes more often than subjects in the NoVLTs group. However, having examined the data for individuals (Table D.3.1 and D.3.2 in Appendix D), we found that there were two subjects in the VLTs group who did not use the diagram mode predominately like all others. It was these exceptions that caused the imbalance between two groups in terms of the use of jumping modes described above. The imbalance disappeared when the two subjects were excluded. We attempted to find out from their think-aloud and interview data the explanation of why the two subjects were behaving so differently from the others. Unfortunately, nothing helpful was found. However, it was observed that both of these subjects performed better than average in the post-test.

As in the method used in Study One, subjects' navigational paths were first transformed into directed-graph-like representations, and then compared and classified into patterns. What differed from the previous method was that we also paid attention to subjects' use of different jumping modes. A striking navigational scenario was found in both groups. The data from both navigational paths and interview suggested that subjects' study processes could be clearly divided into two phases. The first phase was to browse the knowledge space as completely as possible. Ticks appearing on the browsed nodes in both global and local structure diagrams helped ensure that all nodes had been covered. In this stage, subjects relied mostly on the diagram mode and used the other modes as an auxiliary means. The second phase was to review the materials or to focus on the part that the subject either was particularly interested in or had not fully understood yet. During this period, the index mode and history trail mode were mainly used. What interested us more was that ways in which subjects were browsing during the first phase were found to be quite different. As described in Chapter 5, the hypertext used in this study was organised as a variation of hierarchical structures with some cross-links to facilitate comparisons. Although it looks more like a network as shown in the global structure diagram, in fact the information clusters fundamentally in a hierarchical fashion with more general concepts being located higher up in the structure. We identified three browsing strategies which subjects used in their first study phase. The first one was browsing the hypertext meaningfully by following its embedded hierarchical structure. The second one was the Depth-first-search-like browsing, which was based upon the purely physical structure. The last one was the chaotic browsing, in which the subject was moving through the hypertext seemingly at random. They are illustrated respectively in Figure 6.5. More importantly, it was discovered that two groups differed from each other in the number of subjects who were using different browsing strategies (see Table 6.8).

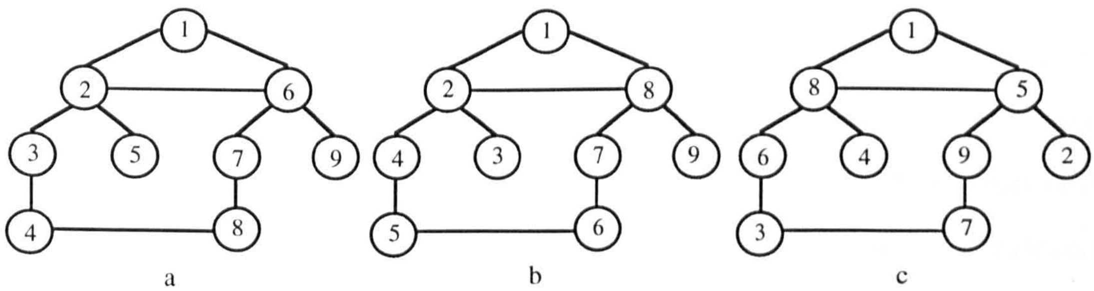

Figure 6.5 Three types of browsing strategies found in the study. a. Hierarchical; b. Depth-first-search-like; and c. Chaotic. Numbers in nodes represent the order in which nodes are visited.

Table 6.8 Differences between two groups in terms of the number of subjects who were taking different browsing patterns.

Link group	Hierarchical	Depth-first-search-like	Chaotic
VLTs	7	7	0
NoVLTs	3	9	1

Learner Satisfaction

Learner satisfaction was probed in this study from subjects' responses to the printed satisfaction questionnaire and by interviews with subjects. The two experimental groups were given the same questionnaire except for one more question for the VLTs group related to labels on connecting lines in the local structure diagram, which was a unique feature of the VLTs version. All questions included in the questionnaire were scale questions and concerned with subjects' subjective satisfaction with the use of the system and their opinion on the design of interface elements (see Appendix C). The subsequent interview was intended to acquire more information about subjects' perception of the system usability. However, close attention was paid to subjects' views on the local structure diagram because it was the local diagram which contained the only difference between the two experimental treatments.

Table C.1 in Appendix C displays subjects' responses to the satisfaction questionnaire. It shows that subjects in the VLTs group spoke more highly of the local structure diagram than subjects in the NoVLTs group (eleven out of fourteen in the VLTs group v. seven out of thirteen in the NoVLTs group said the local diagram was very helpful). The local diagrams of the two hypertext versions differ from each other only in that the connecting line in the local diagram of the VLTs version is labelled using the name of the semantic relation between the two nodes it connects whereas it is just a plain unlabelled line in the local diagram of the NoVLTs version. This suggests a positive impact of visible link-types on users' satisfaction. However, figures in Table C.1 in Appendix C give no indication that the distinction appearing in local diagrams of the two versions caused any significant difference between the two groups regarding subjects' satisfaction with either the use of the system as a whole or the design of other interface elements.

As reflected from subjects' responses to the satisfaction questionnaire, most subjects in both groups expressed the view during interview that they enjoyed using the system and that they found it very easy to use the system. However what we were particularly seeking from the interview was the insight into the difference between the two groups with regard to their opinions on the local diagram. For the same reason given in the last paragraph, the following comments by subjects of the VLTs group on labels attached to links in the local diagram might offer some explanations as to why the local diagram of the VLTs version was more appealing.

> "They [labels] are useful in catching the meaning because I can look at it and think what it is going to be about, where it comes in the whole thing."
>
> "The labels are helpful to understand the text."

"Definitely, they [labels] probably gave me a good indication of where I should go next."

"Labels are helpful because it shows the relevance between two [nodes], and it shows you what the two have got to do with each other, and it is another help in deciding which one you are going next."

"Making decisions and choices is really worth looking at this kind of labels."

The above users' comments have identified two aspects of the usefulness of the labels on links. One is to help users understand the text, the other is to facilitate users' decision-making in navigation. This confirms further our assumptions about the visualisation of link-types which was described in Chapter 3.

In addition, the interviews with subjects provided suggestions for improving the system. They are summarised in the following five points.

(1) Allowing users to jump to any node just by clicking on it in either global or local diagrams;
(2) Showing users the name of a node in a certain way when the node is pointed in the global diagram;
(3) Marking the nodes visited in an index as in the diagrams;
(4) Highlighting hotpoints in the text area more distinctly; and
(5) Keeping displaying small textual windows attached to hotpoints without having to hold the mouse down.

6.3.3 Implications and Discussion

The results found from this study suggest that explicitly labelling links with semantic relations has a positive influence on goal-oriented learning in an explicit semantic net hypertext system. Firstly, the analysis of learning processes showed that a larger percentage of subjects in the VLTs group were adopting a meaningful browsing strategy during the first study phase than that in the NoVLTs group (see Table 6.8). Secondly, subjects in the VLTs group reported a higher level of satisfaction with the local structure diagram than subjects in the NoVLTs (see Table C.1 in Appendix C), while the main distinction between local diagrams of two hypertext versions lay in whether or not links were labelled explicitly with semantic relations. Moreover, the interview with subjects in the VLTs group provided insight into their appreciation of such labelling, i.e., its usefulness for text understanding and decision-making in navigation, which agreed with our hypothesis on visualisation of link-types.

Although learning outcomes did not appear to give credit to visible link-types, this might be due to several factors. Unlike the embedded semantic net system used in Study One, the explicit semantic net hypertext used in this study provided learners, through the local diagram, with not only the name of the current node but also names of all nodes adjacent to the current one. This would possibly enable learners to work out, without other clues, the appropriate semantic relationship between two connected nodes (Chaffin & Herrmann, 1988). In addition, reading the content included in the current node also helped this task as reported by a subject in the interview: " I think once you read the text, most people would be able to work out the relationship between nodes." On the other hand, because of the modest scale of the knowledge domain and the provision of structure diagrams, no severe phenomenon of cognitive overload expected to occur in navigating a "real" hypertext system was observed or reported in either group. This could have significantly obscured the treatment's effects on learning outcomes.

In contrast to a unique strategy found in the previous study, three different browsing strategies were recognised in this study despite the similar structure of the two hypertext versions. This seems to conflict with Parunak's assumption (Parunak, 1989, 1991), that is, the availability of navigational strategies in hypertext depends on the topology of the hypertext. As far as we are concerned, there must be a variety of factors that would affect the navigational strategy applied by a user, such as hypertext topology, interface design, navigation tools, learning objectives, and learner individual differences. In fact, we have come to a very interesting research topic, but it is beyond the scope of this thesis.

The results of this study supported the finding from Study One that subjects' individual differences in prior knowledge played a mediational role in differentially designed treatments. Subjects' prior knowledge was related positively and significantly to their performance in both parts of the post-test across both experiment treatments ($r=.71$, $r=.87$; $r=.62$, $r=.69$) (see Table D.2.1 and D.2.2 in Appendix D).

6.4 Study Three

Hypertext learning environments have been thought of as more suitable for exploratory learning applications where no specific objectives are fixed since hypertext shares many of the characteristics that are integral to exploratory learning (Heller, 1990). Such a learning task is different from the goal-oriented one used in former studies in that they involve different cognitive processing. The main purpose of this study was to investigate the effects of visualisation of semantic relations between nodes on exploratory learning in an explicit semantic net hypertext. As in the previous studies, the investigation was undertaken by comparing learning gains, learning processes, and leaner satisfaction under two experimental conditions. In order to assess learning outcomes more extensively, besides a multiple-choice questionnaire, a teach-back test was introduced into this study, which was similar to the free-recall test. Both tests (multiple-choice and teach-back) consisted of two aspects, namely structural knowledge acquisition and specific nodal information gains. In addition, the relationships between learners' spatial and verbal abilities and the impact of visible link-types on learning were also examined. The purpose was to see if the property of visualising semantic relations has different effects on students who differ in these two abilities.

6.4.1 Method

Participants

Twenty four paid subjects, who were first-year undergraduate students at the School of Computing & Mathematical Sciences, De Montfort University, Milton Keynes, took part in the study. They were randomly divided into two equal-sized groups without regard to gender, namely, a control group and an experimental group.

Learning Materials

The same explicit semantic net hypertext as used in Study Two was used as the learning material. Its two versions (VLTs vs. NoVLTs) were taken as two different experimental conditions in the study.

Instruments

As in the former two studies, three basic testing instruments (see Appendix E) were applied in this study. The first was a printed self-assessment as was used in Study Two. The second was a printed learning assessment questionnaire to investigate subjects' structural knowledge and nodal information gains, which covered the learning materials more widely than that used in Study Two. It also had two parts. The first part was the same as that used before, but the second part included five more questions. The third was a scale questionnaire accompanied by interviews for investigating learner satisfaction.

In order to assess subjects' spatial and verbal abilities, two reliable and commonly used tests were adopted in this study. The test used for spatial abilities was GEFT (Group Embedded Figures Test published by the Consulting Psychologists Press), which requires participants to locate a series of simple geometric shapes embedded within more complex geometric patterns. The test used for verbal abilities was Delta (Delta Reading Vocabulary Test published by the Air Force Human Resources Laboratory, Lowry Air Base, CO.), which consists of single target words followed by five options. The participant's task in the Delta test is to indicate the option word that is synonymous with the target.

In addition, two scoring keys to evaluate teach-back results were developed. One was for structural knowledge gains, the other for nodal information gains. The scoring key for structural knowledge gains consisted of a set of propositions which covered the structural knowledge of the learning material. Each of these propositions was presented by a simple declarative sentence. A subject's structural knowledge gains were measured by matching propositions in the scoring key with the idea units contained in his teach-back protocol. For each proposition that appeared in both the key and a subject's protocol, the subject received a score from 1 to 3 depending on the accuracy of the match. The scoring key for nodal information gains comprised the catalogue of contents included in the material. A subject's nodal information gains were measured by matching the catalogue with the description found in his teach-back protocol. For each match, the subject was assigned a score from 1 to 3 depending on how detailed and accurate his description was. Reliability of this scoring method was established by having another evaluator score each protocol, and the results showed a significant positive association ($r=.91$) between the two sets of scores.

Procedure

First of all, subjects were asked to complete the self-assessment form. Then they were administered the Delta (10 min). Following this, they were exposed to a specific version of the experimental hypertext system according to which group they had been randomly assigned. The VLTs version was used in the experimental group and the NoVLTs version was used in the control group. Before starting to work through the hypertext, subjects received a brief introduction to the use of the system and were instructed to work at their own pace without having time limits. Subjects were informed that on finishing their study with the hypertext they would be tested on the information it contained. As in Study Two, they were also requested to verbalise their thoughts as far as possible during their interaction with the hypertext. As soon as they felt their interaction was complete, the subjects began the post-test. This involved: teaching back what was learned from the hypertext; completing the multiple-choice learning assessment questionnaire; responding to the satisfaction questions; and being interviewed by the experimenter. Finally, the GEFT was carried out (18 min). The procedure of the teach-back test is rather simple. The subject was asked to give the experimenter a short lecture on the topic the experimental hypertext covered. The experimenter, as a facilitator, would not interrupt the subject, but would encourage her/him to say as much as she/he could recall when a longer pause occurred. The whole teach-back as well as the interview were tape-recorded.

As in the last study, monitoring scripts contained in the experimental hypertext system automatically captured user navigational paths and a video camera was set to record think-aloud protocols together with corresponding scenes.

6.4.2 Results

Learning Outcomes

In Table 6.9, the figures under Multiple 1 and Multiple 2 represent the mean correct percentage of scores and their standard deviations for each part (i.e. structural knowledge vs. specific nodal information) of the multiple-choice learning assessment questionnaire while the figures under Teach-back 1 and Teach-back 2 represent the mean percentage of gained scores to the full scores and their deviations for each part of the teach-back test. Correlation analysis indicated that none of three independent variables (i.e. subjects' self-assessment of prior knowledge, Delta scores, and GEFT scores) was correlated highly and consistently with any dependent variables (i.e. multiple-choice part one, multiple-choice part two, teach-back part one, and teach-back part two) across either groups except for Delta vs. multiple-choice part two ($r=.45$, $r=.58$) (see Table F.2.1 and F.2.2 in Appendix F). However, the difference between two groups on the mean scores of multiple-choice part two became even smaller after the group means were adjusted for the differences in Delta because the initial difference was in favour of the VLTs group (see Table F.1.1 and F.1.2 in Appendix F). Therefore, no independent variables were chosen as covariates to adjust the post-test scores.

Table 6.9 Means and standard deviations of percentage on post-test scores as a function of link group.

Link group	Structural (multiple-choice)	Nodal (multiple-choice)	Structural (teach-back)	Nodal (teach-back)
VLTs (n=12)	50.83 (9.96)	63.89 (18.08)	14.74 (8.41)	17.26 (9.42)
NoVLTs (n=12)	50.00 (24.86)	61.11 (20.66)	9.19 (6.51)	13.10 (8.03)

A column chart (Figure 6.6) of the data represents a clearer picture of differences of learning outcomes between the two experimental groups.

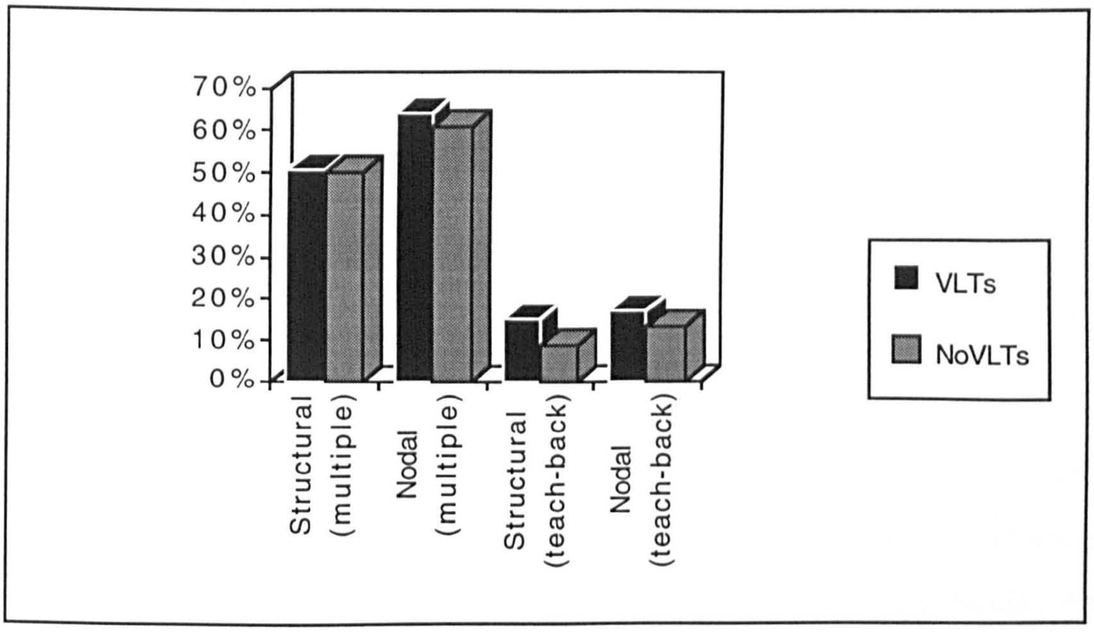

Figure 6.6 Means of percentage scores on post-tests for the two experimental groups.

An examination of Table 6.9 revealed that subjects in the VLTs group performed better than subjects in the NoVLTs group over all the post-tests. However, it was obvious that the differences between the two groups on multiple-choice scores were so trivial that they could be ignored. The differences on teach-back scores were quite large. A *t*-test yielded $t=1.81$, $p=.04$ (one-tail) for the first part and $t=1.17$, $p=.13$ (one-tail) for the second part respectively (see Figure F.1.1 and F.1.2 in Appendix F). It confirmed that subjects in the VLTs group did significantly better than subjects in the NoVLTs group in recalling the structural knowledge of the domain. Although subjects in the VLTs group also did much better than those in the NoVLTs group in recalling specific nodal information, the difference was not significant statistically.

Learning Processes

As in Study Two, learning processes were analysed by means of a set of performance indicators, learner navigational tracks and data collected from the think-aloud protocols and interviews.

Table 6.10 A set of performance indicators: means (standard deviations) of data in relation to subjects' actions.

Link group	Total browsing time (min)	Total cards browsed	Different cards browsed	"Diagram" mode	"Index" mode	"Back" mode	"Recent" mode
VLTs	43.0 (10.9)	46.8 (11.6)	22.0 (0.0)	36.5 (9.9)	5.3 (9.2)	2.6 (3.3)	1.4 (2.5)
NoVLTs	44.6 (13.2)	56.7 (32.7)	22.0 (0.0)	40.8 (12.9)	5.8 (12.9)	6.8 (10.4)	2.3 (4.9)

Table 6.10 shows a set of performance indicators, including the browsing time, the number of cards browsed, the sum of different cards browsed, and the times of using different jumping modes (see Table F.3.1 and F.3.2 in Appendix F for details). An examination of Table 6.10 revealed that subjects in the NoVLTs group explored their hypertext more extensively than subjects in the VLTs group, in terms of visiting a larger number of cards than subjects in the VLTs group. Using the concepts of completion rate and repetition rate defined in section 6.2.2 relating to Study One, the repetition rate of the NoVLTs group was higher than the VLTs group's (R_{NoVLTs}=*2.6*, R_{VLTs}=*2.1*) although the two groups had the same completion rate. It was also revealed that the diagram jumping mode was used significantly more than other modes for both groups but the two groups varied in using different jumping modes.

Table 6.11 Mean percentages of jumping through different modes to total jumping.

Link group	"Diagram" mode	"Index" mode	"Back" mode	"Recent" mode
VLTs	79.7	11.6	5.7	3.1
NoVLTs	73.2	10.4	12.2	4.1

To identify more explicitly the difference between the two groups in their use of jumping modes, the average percentages of jumping by different modes to total jumping were worked out as shown in Table 6.11 as well as its 3-D column chart (Figure 6.7). This shows us that subjects in the VLTs group applied diagram and index modes more frequently than subjects in the NoVLTs group, while subjects in the NoVLTs group used back and history trail modes more frequently than subjects in the VLTs group.

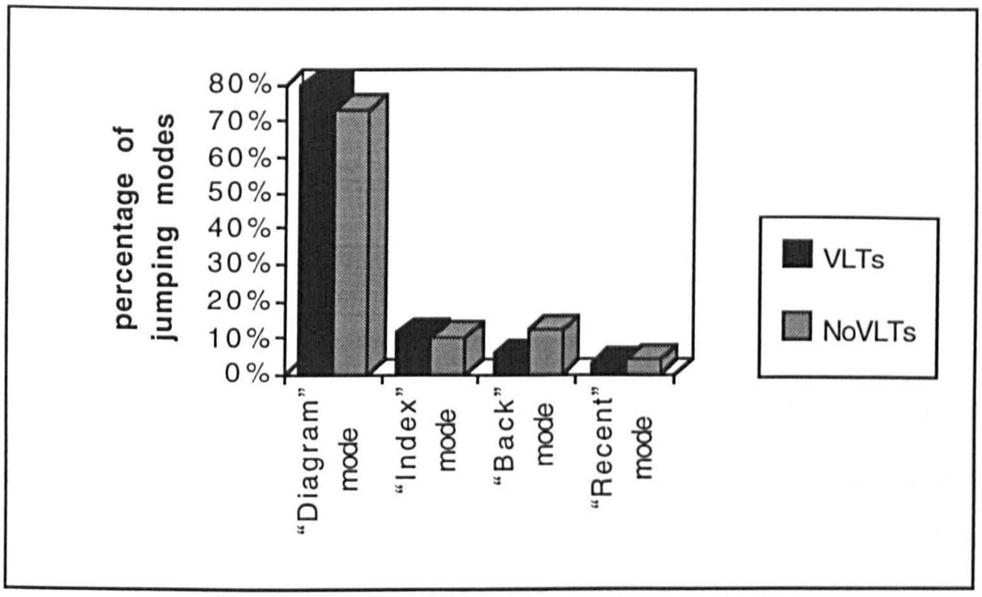

Figure 6.7 Differences between two groups in the use of jumping modes.

As in Study Two, subjects' navigational paths with the property of jumping modes were first transformed into directed-graph-like representations, and classified into patterns. Unlike Study Two, the scenario of two studying phases did not appear so strikingly in this study. A large proportion of subjects in both groups finished their study immediately when they had covered all nodes, with all nodes in the global structure diagrams being ticked. This gives an evidence that learning tasks have an influence upon users' interaction with hypertext systems.

The three kinds of browsing strategies identified in Study Two were also applicable to the analysis of subjects' navigational paths for this study. Like the finding from the last study, it was found that the two experimental groups contrasted with each other by the number of subjects who were employing different browsing strategies (see Table 6.12) and that again a larger percentage of subjects in the VLTs group used a meaningful (hierarchical) browsing method.

Table 6.12 Differences between two groups in terms of the number of subjects who were taking different browsing patterns.

Link group	Hierarchical	Depth-first-search-like	Chaotic
VLTs	9	3	0
NoVLTs	6	4	2

Learner Satisfaction

In this study, we assessed learner satisfaction by the method used in Study Two. Printed scale questions were used to elicit users' subjective satisfaction with the use of the system and their view on the design of interface elements. Interviews with subjects were carried out to acquire more information on their perception of the system usability. Our emphasis was again on subjects' attitudes towards the local structure diagram because this was the significant difference between the two experimental conditions.

Table E.1 in Appendix E shows subjects' responses to the satisfaction questionnaire. As in Study Two, it is clearly seen that subjects in the VLTs group praised the local structure diagram more highly than did subjects in the NoVLTs group. Ten out of twelve in the VLTs group versus seven out of twelve in the NoVLTs group said the local diagram was "very much" helpful. Same as in Study Two, the response to the satisfaction questionnaire gives no indication that the distinction appearing in local diagrams of two versions caused any significant difference between two groups regarding subjects' satisfaction, with either the use of the system as a whole, or the design of other interface elements.

Consistent with their responses to the satisfaction questionnaire, most subjects in both groups expressed in interviews their enjoyment and comfort in working on the hypertext system. As in the last study, we were particularly interested in the comments made by subjects of the VLTs group on visualisation of semantic relations in the local diagram. Some of them are reproduced here.

> "[Labels] help find the way around, explain what it is going to show you, and give the idea of what you are going to see if you select that."
>
> "..... because it [label] tells you what the next part will be, what the next link is actually about. For example, you got 'static lists represented by arrays.' It is exactly telling the user 'the array is used to represent the static list.' So, they want to find what they are and go there."
>
> "By looking at it [label], you get the picture of the whole model exactly we are working with."

Additional suggestions for improvements were made, students adding two more points as follows:

(1) Using colours could make labels on links more outstanding;

(2) Text on some cards is over full. The spacing between lines ought to be made larger to aid readability.

6.4.3 Implications and Discussion

The results from this study suggest that explicitly labelling links with semantic relations has a positive influence on exploratory learning in an explicit semantic net hypertext system. First of all, the learning outcomes showed that subjects of the VLTs group achieved more than subjects of the NoVLTs group over all aspects of the post-test, especially in the teach-back test (see Table 6.9 and Figure 6.6). Secondly, the analysis of learning processes also showed that subjects of the VLTs group performed better than subjects of the NoVLTs group in terms of the navigational quality as a whole. This is drawn from the fact that a larger percentage of subjects in the VLTs group adopted a meaningful browsing strategy in their interaction with the hypertext. Finally, subjects of the VLTs group expressed a higher degree of satisfaction with the local structure diagram (see Table E.1 in Appendix E), and their comments about labels on links clearly supported our assumption about the visualisation of link-types.

Although subjects of the VLTs group scored more highly than subjects of the NoVLTs group in all four post-test tasks, in recalling the structural knowledge of the domain, subjects in the VLTs group did significantly better than their counterparts. This implies that visualisation of semantic relations between nodes can particularly facilitate users' structural knowledge acquisition.

The existence of multiple browsing strategies adopted by subjects in this study further supports the argument we raised in the last study that there must be various factors that would affect users in their application of strategies for navigation. The reasons why subjects of the NoVLTs group explored the hypertext more extensively and why subjects in the VLTs group applied diagram and index modes more frequently than subjects in the NoVLTs group, while subjects in the NoVLTs group used back and history trail modes more frequently than subjects in the VLTs group, is rather unclear. The difference may be in fact caused by chance since it is not significant statistically.

In this study, we also examined the relationships between (1) subjects' verbal ability and their performance on the post-test as a function of the hypertext version; and (2) subjects' spatial ability and their performance on the post-test as a function of hypertext version. In order to do so, Delta scores and GEFT scores were used to form a second between-group variable. Then all subjects were respectively median-split into high (n=12) and low (n=12) verbal ability groups, and high (n=13) and low (n=11) spatial ability groups. Table 6.13 and 6.14 show the mean percentages for each post-test task as a function of hypertext version and verbal ability, and a function of link group and spatial ability respectively.

Table 6.13 Means of percentage on post-test scores as a function of hypertext version and verbal ability.

Delta	Structural (multiple-choice)		Nodal (multiple-choice)		Structural (teach-back)		Nodal (teach-back)	
	VLTs	NoVLTs	VLTs	NoVLTs	VLTs	NoVLTs	VLTs	NoVLTs
Low	50.00	44.29	53.33	56.19	14.36	8.06	15.71	13.27
High	51.43	58.00	71.43	68.00	15.02	10.77	18.37	12.86

Table 6.14 Means of percentage on post-test scores as a function of hypertext version and spatial ability.

GEFT	Structural (multiple-choice)		Nodal (multiple-choice)		Structural (teach-back)		Nodal (teach-back)	
	VLTs	NoVLTs	VLTs	NoVLTs	VLTs	NoVLTs	VLTs	NoVLTs
Low	48.33	34.00	60.00	54.67	13.25	7.69	18.45	10.00
High	53.33	61.43	67.78	65.71	16.24	10.26	16.07	15.31

An examination of Table 6.14 revealed that the low spatial ability subjects in the VLTs group did better than the low spatial ability subjects in the NoVLTs group throughout all parts of the post-test while the same phenomenon did not occur in subjects with high spatial abilities. It seemed to suggest that the learners with lower spatial abilities take more advantage of visualisation of semantic relations. This is similar to the finding from Study One, that is, learners with lower prior knowledge could benefit more from visible link-types. However, the relationship between subjects' verbal ability, their performance in post-test, and hypertext versions used is rather ambiguous (see Table 6.13).

6.5 General Implications and Discussion

The results of the present series of empirical studies have confirmed to differing extents our hypothesis, that is, labelling links explicitly with semantic relations between nodes can improve learning with hypertext-based learning systems. This is because except for the specific results relating to learning processes in Study One and learning outcomes in Study Two, which were rather ambiguous, all results demonstrated a positive impact of visible link-types on learning. Now let us look further into the two exceptional situations where the two treatments did not cause apparent differences between the two groups. First, we believe that the lack of sophisticated navigational assistance in the hypertext system used in Study One could have significantly diminished the treatment's effects on users' interaction with the hypertext system. This might explain the lack of a distinction between the two experimental groups in learning processes, which we expected to appear. Second, having compared Study Two with Study Three, we see an interacting impact of learning tasks and hypertext versions on learning outcomes. Study Two and Study Three can, in fact, be viewed as two treatments of a single study because the primary difference between the two studies lay only in the fact that one used goal-oriented learning and the other used exploratory learning as respective learning tasks. In such a study, the effect of visible link-types on learning outcomes emerged under the treatment of the exploratory learning task (i.e., Study Three), while such effects disappeared under the treatment of the goal-oriented learning task (i.e., Study Two). The possible reason for this phenomenon is that learners who have clear learning goals might be prompted to work out the appropriate semantic relationships assigned to most of the links from the structure diagrams and by reading text even without the help of visible link-types. Furthermore, learning tasks seemed to have had an influence on learning processes to some extent. Without fixed learning objectives, learners tend to feel more free to explore the hypertext. This point is supported by the following three statistics: the average time spent on working with hypertext in Study Three was thirty percent longer than that in Study Two (*$t=2.44$, $p=.018$, two-tail*); the average number of cards browsed in Study Three was thirteen percent larger than that in Study Two; and the subjects using the VLTs version in Study Three allocated more than twelve percent longer time to each card than subjects using the same version in Study Two. This suggests the possibility that learners without a fixed learning goal in Study Three paid more attention to visible link-types than the goal-oriented learners in Study Two. This offers a possible explanation for the higher level of achievement obtained by subjects using the VLTs version in Study Three.

Both Study One and Study Two demonstrated that subjects' individual differences in prior knowledge played a mediational role in differentially designed treatments. In other words, learners' prior knowledge overshadowed the influence of visible link-types in the first two studies. However, we did not carry out the same analysis in Study Three because the definition of prior knowledge could no longer be fulfilled in the study. Alternatively, we examined separately the relationships of subjects' verbal and spatial abilities and their performance on the post-test as a function of hypertext versions. Results seemed to suggest that subjects' verbal and spatial abilities were predictors of their performance in the post-test in both situations (i.e., with or without visible link-types). In almost all cases subjects with higher Delta scores did better than with lower Delta scores and subjects with higher GEFT scores did better than with lower GEFT scores as well for both VLTs and NoVLTs.

The think-aloud approach in the last two studies was intended to provide some insight into the user interaction with the hypertext systems. Unfortunately, it did not live up to what we expected initially in the following senses. Only a small percentage of subjects were "thinking aloud" during their studying sessions as requested, and what they uttered was mainly just either repetition of words in the text passage they were reading or names of nodes they were going to. The former is hardly useful while the latter is redundant because the same information was recorded by the monitoring scripts. The following factors might be responsible for this. First, provision of structure diagrams in the hypertext probably eased subjects' difficulties in choosing which links to follow so that they might not have had much to say. Secondly, interaction with hypertext is quite different from interaction with a human being, so that requiring users to keep verbalising that interaction might be asking them to behave in a way which they find unnatural.

6.6 Summary

The results of the set of three empirical studies have suggested that our proposed approach has positive influences on learning. More specifically, compared with those viewing no link-types, subjects viewing link-types gained more in terms of learning outcomes, performed better in the sense of the navigational quality, and felt more satisfied with the use of the hypertext systems. In addition, we have also derived a number of interesting findings from the studies, which are not the main stream of our studies but help us understand better the effectiveness of visible link-types in hypertext. They can be summarised into the following five points.

- The learner's prior knowledge might have a larger effect on learning outcomes than visible link-types. (Study One and Two)

- The learner with lower prior knowledge might benefit more from visible link-types than the learner with higher prior knowledge. The learner with lower spatial ability might take more advantage of visible link-types. (Study One and Three)

- Visible link-types might be more beneficial for structural knowledge acquisition than nodal information gain. (Study Three)

- There seem to be more factors than simply network topology affecting the strategies users apply for navigation. (Study Two and Three)

- The nature of the learning task appears to have an interacting influence with visible link-types on both learning outcomes and learning processes. (Study Two and Three)

Some issues that emerged in the studies merit further investigation. A number of these, as well as other research problems raised earlier, will be discussed in the next and final chapter.

Chapter 7 Conclusions and Further Work

7.1 Introduction

This final chapter summarises the main achievements of the research presented within this thesis, provides a critical evaluation of the work, and proposes two levels of further work: elaborating the findings from the current studies and extending the current research.

7.2 Achievements

The main achievements of the research reported within this thesis can be divided into five categories: designing hypertext for learning, evaluations of hypertext-based learning, human-computer interface design, knowledge representation, and design and implementation of experimental hypertext systems

Designing Hypertext for Learning

The educational use of hypertext seems to have already reached a stage at which although its efficacy has not been established and it is not problem free, it is seen as a teaching/learning medium. Researchers and designers of educational hypertext have meanwhile been constructing guidelines for developing effective instructional hypertext systems. A great deal of work in this area appears in the literature (Hammond, 1993; Hutchings et al., 1992; Jonassen, 1986; Kearsley, 1988; Shneiderman, 1988; Wilson & Jonassen, 1989; Landow, 1989; Jonassen & Mandl, 1990). An updated overview of guidelines relating to hypertext-based courseware development can be found in a recent survey article by Poncelet and Proctor (1993). One of the main achievements of the research described in this thesis is to have added a new dimension to such guidelines, which can be summarised as the concept that visualisation of semantic relationships between nodes facilitates learning with hypertext-based learning systems.

The application of hypertext in educational settings is relatively new. It is necessary for educational hypertext designers to obtain principles from cognitive learning theory and it is also reasonable for them to borrow ideas from various related areas such as instructional design and traditional CAI design. Do these principles and ideas fit well in the situation of designing hypertext for learning? The only way to answer this question is to test them empirically. As indicated in Chapter 2, some attention has been drawn to the importance of visible link-types in hypertext (Parunak, 1991; Collier, 1987; Jonassen & Grabinger, 1990), but no studies have seriously examined how important they are. The effectiveness of visible link-types in hypertext had remained an untested assumption before this study. The current research has partly filled this gap by investigating the effects of visible link-types on goal-oriented and exploratory learning with both embedded semantic net and explicit semantic net hypertext.

Evaluations of Hypertext-Based Learning

Since our assumption is concerned with the effects of the proposed interface design on learning, testing the assumption virtually turns into the matter of evaluating hypertext-based learning. However, the methodology of assessing learning with hypertext has not yet been well developed. Marchionini (1990) believes that "the essential problem of evaluating highly interactive systems is in measuring both the quality of the interaction as well as the product of learning." Thus, he suggests that evaluations of hypertext-based learning must address both learning processes and learning outcomes. Furthermore, he proposes a multi-faceted approach to such evaluation with particular emphasis on the learning process. The evaluating method used in our research is based upon the framework proposed by Marchionini.

However, in this thesis this framework has been enhanced by examining learner subjective satisfaction besides learning outcomes and learning processes. The multi-faceted approach has also been enriched by incorporating Pask and Scott's teach-back test (Pask, & Scott, 1972) in assessing learning outcomes and the graphical navigational pattern comparison in analysing learning processes. It is clear that the evaluation process used in this thesis is an application of Marchionini's multi-faceted approach on the one hand, and a further development of his method on the other hand. The evaluation of learning conducted as part of this research can be more generally viewed as a systematic practice of evaluating hypertext usability. The evaluation of hypertext usability is currently still in the nature of conjectures based on personal experience (Nielsen, 1990c).

Human-Computer Interfaces

Hypertext is a highly interactive computer application. Its usability is highly dependent on its interface design. Many unsolved issues concerning hypertext are in the user interface area (Nielsen, 1990b). The most commonly identified problems with hypertext such as disorientation and distraction in navigation are definitely related to interface design. This thesis focuses on the issue of interface design in an attempt to mitigate the navigational difficulties so as to improve the system usability. It has been found that labelling links explicitly with semantic relations between nodes does facilitate improvement of the system usability in terms of better learning outcomes, higher navigational quality, and a higher degree of subjective learner satisfaction. Although this thesis is set within the context of designing hypertext for learning, the findings from it certainly have broader implications for generic hypertext interface design.

Knowledge Presentation

Although people in the area have noted the likeness between hypertext and semantic networks and assumed hypertext as a knowledge representation conveying more than just information (Conklin, 1987; Jonassen, 1990; Tsai, 1988), no systematic comparisons between hypertext and semantic networks have been made in the literature. Despite the existence of a number of experimental hypertext systems claiming to have semantic networks as their frameworks (Collier, 1987; Trigg, 1983; Fairchild et al., 1988), none of them paid much attention to establishing comprehensive principles for expressing and representing semantic relations in hypertext. Both issues are important because the features of hypertext as a knowledge representation can be more clearly and more easily identified by contrasting hypertext with semantic networks and also because a set of general principles for expressing and representing semantic relations is essential for any knowledge presentation. Chapter 3 of this thesis was devoted to addressing these issues, where hypertext and semantic networks were compared in terms of knowledge representations; a preliminary taxonomy of semantic relations was established; some important properties of semantic relations were discussed; a way of expressing and displaying semantic relations was proposed; and finally the limitations of this method were identified. This work has established a useful, though preliminary, theoretical basis for building hypertext as knowledge representations.

Design and Implementation of Experimental Hypertext systems

Despite the fact that the hypertext systems used in the research were designed to satisfy our specific research criteria, the systems, especially the explicit semantic net hypertext system, were praised highly by the users and are useful for students who want to learn the basic concept about data structure in computing. Below are some comments made by subjects.

> "I really enjoyed using it. I think it was very worthwhile exercise of learning Data Types. I have done Data Types before in A levels. I had lectures, papers. If we had this, something could be a lot easier because if you weren't sure you could go back, go to the index. Also the demo is very useful. You can take quite a long while to pick it, set it up, work it out. But you had them in a couple of seconds appear in the screen."
>
> "Really it was a good fun to use. I never used a system like that before. Especially with the global diagram on the map to show you exactly the way around."
>
> "It is enjoyable to use. It is definitely a good idea to have the global diagram to show you way about. Very helpful. I think it is a very good system actually."

In addition, the task of developing the experimental hypertext systems provided an opportunity to experience the whole process of building a hypertext-based learning system by using a hypermedia authoring package such as HyperCard. This process includes selection of learning materials and authoring tools; design of information models, navigational tools and user interfaces; and finally implementation of the system. The design of information models was the most challenging sub-task. This is because we are used to ways of structuring knowledge to suit the linear print medium while hypertext encourages the non-linear interconnection of links among fragments of text, which is not easy with the conventional print medium and is new to us. Restructuring knowledge to suit a new medium is not without problems (Whalley, 1993). This task of modelling information for experimental systems has contributed to the growing body of expertise in this area.

To summarise, the research presented in this thesis has achieved the following:

(1) It has proposed a new guideline for designing hypertext-based learning systems, that is, visualisation of semantic relationships between nodes in hypertext-based learning systems. More importantly, it has tested the effectiveness of this guideline empirically.

(2) It has improved and practised Marchionini's method of evaluating hypertext-based learning. More generally, it has also enriched our experiences and knowledge on the evaluation of hypertext usability.

(3) It has examined an important parameter of interface to hypertext-based learning systems, that is, denotation of links. The findings from this examination is beneficial to the generic hypertext interface design.

(4) It has established a preliminary theoretical basis for building hypertext as knowledge representations, identifying important properties of semantic relations; a method of expressing and displaying semantic relations in hypertext, and the limitations of this method.

(5) It has produced two hypertext systems, which are useful for students who want to learn the basic concepts about data structures in computing.

7.3 Criticisms and Limitations

A criticism has been directed at the first study, i.e., the study investigating the effects of visualising semantic relations between nodes on goal-oriented learning in an embedded semantic net hypertext. In this empirical study, the independent variable is the hypertext version, which has two conditions: with or without visible link-types. In the version with visible link-types, however, the semantic relations are visualised differentially for associative links and referential links. The associative link is directly labelled by using the name of the semantic relation between the two nodes it connects whereas the referential link is indirectly labelled by attaching to it a small palette which contains the semantic relationship between the reference and its referent and which is visible only when the link is pointed. The question is raised that to which factor, visible link-types on associative links or visible link-types on referential links, the difference in performances between two experimental groups should be attributed. The study failed to answer this question because the two factors were examined as a single condition of the independent variable in the study.

Another criticism is that the research presented in this thesis could have been more complete if it included a study investigating the effects of the visualisation of semantic relations on exploratory learning with the same hypertext as used in the first study. This is because it is believed that hypertext is more suited to exploratory learning than goal-oriented learning. Therefore, the emphasis of our research should be placed on the effects of visible link-types on the exploratory learning. Now that we examined both goal-oriented and exploratory learning in the case of explicit semantic net hypertext, what is the reason for considering only the goal-oriented learning in the case of embedded semantic net hypertext?

The following are some technical weaknesses existing in the current research. They are likely to be improved by applying appropriate techniques, which will be taken up as future work in the next section.

(1) In the current research, the analysis of patterns of user interactions with hypertext systems is based on the DG (Directed Graph) representations of users' navigational paths. The transformation of the computer captured navigational data into the DG representation is done manually. This method will become impractical when users' navigational scales get larger.

(2) In the explicit semantic net hypertext used in Study 2 and 3, both global and local structure diagrams were generated by hand. Obviously, the automatic generation of such graphical browsers as in NoteCards is essential for a "real" hypertext system.

(3) In the explicit semantic net hypertext, the local diagram displays the current node, together with all nodes that connect to it by one or two levels of associative distance, no matter how far these nodes are physically away from the current node in the global diagram. It is clear that the shape of the local diagram can not be always represented consistently with its existence in the global diagram, which causes confusion to users when they try to locate the next node they want to visit in the hyperspace.

Due to the modest scale of the hypertext systems used in the studies in the sense of both the domain of content and the complexity of interrelationships, no severe phenomena of cognitive overload and disorientation was observed or reported in the empirical studies. This factor has weakened the generality of the findings from the current research. A question which must be addressed in the future is whether visualisation of semantic relations between nodes will scale up to more complex systems and still prove to have the advantages demonstrated in this research.

7.4 Future Work

It is suggested that the further work in relation to the current research should be broken down into two phases. The immediate next steps should be to elaborate the existing work, and the longer term further work would be to extend the existing findings on a wider scale than explored in this thesis.

Elaboration of Existing Work

If the research could be continued, the first step would be to complete the experiment which examines how visible link-types affect exploratory learning in the case of embedded semantic net hypertext. This would lead to a better understanding of the effectiveness of the proposed approach in both explicit semantic net hypertext and embedded semantic net hypertext. In addition, separate studies examining visible link-types on associative links and on referential links in the case of embedded semantic net hypertext should be carried out. The purpose of such studies is to identify more precisely which factor, visible link-types on associative links or visible link-types on referential links, contributes most to the increased effectiveness.

Extensions of Current Research

Although the findings from the current research are of interest in their own right, further studies are needed to generalise them by examining empirically the validity of the proposed method in more complex hypertext systems. There are at least three key issues that need to be addressed in order that future empirical studies can be carried out: (1) the issue of semantic relations, including properties of semantic relations, types of semantic relations, and ways to express them; (2) the issue of evaluation methods; and (3) the issue of developing complex hypertext systems as software platforms for the studies. In the present research, we have established bases for the first two issues, but both need to be adjusted and augmented to meet the requirements of future studies of larger scale systems. For example, in future studies the analysis of user navigation patterns must be at least partly computerised because of the larger amount of navigational data which it would be impractical to analyse manually as in the current studies.

Our investigation of existing hypertext authoring systems has shown that none of them satisfies our research demands of supporting visualisation of semantic relations between nodes in the resulting hypertext. Therefore, the proposed long term further work should include creating an innovative hypertext authoring system which supports visualisation of link-types. Some important features of this authoring system will be described in the next sub-section.

Further study should investigate the efficacy of visualising link-types in the real setting rather than in the laboratory. As in the current studies, the computer monitoring would be the main means of collecting user interaction data, but the data analysis would be more computerised because it is impractical to study a large amount of data manually. As suggested by Nelson et al (1993), characterising the interactions of individual users, or comparing groups of users can be accomplished using several methods derived from mathematical set and graph theories. For example, path algebra can be used to describe and compare the routes users take through hypertext systems, and graph theory can be employed to construct network representations of user interactions. Methods of monitoring and evaluation of general information system usage (Penniman & Dominick, 1980; Rice & Borgman, 1983) should be examined and then adapted to cater for the requirements in the proposed further study. The work suggested above for extensions of the current research is quite large. It would require a minimum of 3 person years to complete.

A Proposed Authoring System

The system would help authors to model a specified knowledge domain as a semantic network by organising concepts in the form of nodes and connecting them by links. Compared with other existing hypertext authoring systems, the system would possess a unique characteristic, i.e. providing facilities to realise link-type visualisation and link filtering.

The system would be able to automatically generate a fisheye-view structure diagram for the resulting hypertext according to the author's specification. The diagram would show details near a focal node and only more important nodes as landmarks further away. Such views attempt to give a useful balance of local details and surrounding context. All nodes in the diagram are attached with their thematic titles and all links with semantic relations conveyed by them in any of three forms (i.e., names of relations, or colours or shapes of linking lines) chosen by the author. Using different colours or shapes of linking lines to represent different types of semantic relations is a possible solution to the problem of displaying those relations which need longer expressions. The end-users can use the diagram to navigate through the hyperspace by clicking on any of nodes and they would obtain different views of the hypertext structure from different standpoints. An example of formally generating the fisheye-view diagram is given in Appendix G, which is based on the method created by Furnas (1986).

Research has shown that visualisation of links on the screen becomes unmanageable for the user when the number of links increases. McKnight et al. (1991) point out that "for richly interconnected material or documents of a reasonable size and complexity, it is not possible to include everything in a single browser without the problem of presenting 'visual spaghetti'". Although the fish-eye-view technique can be expected to ease this problem, another approach to it is link filtering, which is designed to filter links according to link-types, i.e. the semantic relations between nodes. More specifically, filtering links would eliminate some of the available links from the display and keep only those links of the types with which the user is presently interested. This approach has been previously suggested in the literature (Parunak, 1991; Tomek & Maurer, 1992). This idea would be realised in the proposed system. The end-user of a resulting hypertext system would be provided with approaches to specifying criteria for filtering links. For example, the end-user can select only causal relationships to look at.

The system would be designed using the object-oriented paradigm. Both nodes and links are viewed as objects, each of which is attached with a set of attributes. Among link attributes, the following are related to the realisation of visualising link-types and link filtering:

TypeName:	The name of the semantic relation between two nodes connected by the link. It is normally a verb phrase.
LinkSource:	The name or number of the node from which the link emanates. Since any relation has sequence, any link in the system is directional. Therefore, it is necessary to distinguish between original and terminal nodes.
LinkDestination:	The name or number of the node to which the link connects.
Visualisation:	One of three optional methods of denoting link-types, i.e. directly attaching TypeName to the linking line, using different colours, or shapes of linking lines, in the structure diagram.
Filtered:	Its value determines whether the current link is filtered. End-users are responsible for this attribute by specifying whether they are interested in the link-type that the current link belongs to. The default value of this attribute would be *false*.

Authors should be able to easily modify any attributes of any objects. The system would have functions to check consistency and completion of authors' specifications in relation to the structure representation. The object-oriented nature of the system should allow authors to add, delete, and modify objects they have created without hidden interactions between those objects.

Another main feature of the proposed system should be its simplicity of use. Its users would be free from learning many trivial skills, e.g. how to create text fields, highlight words and phrases, and produce low level scripts. These skills are necessary to use most existing hypertext authoring environments such as HyperCard, ToolBook, and LinkWay. The proposed system should provide those users who do not have enough time to learn detailed skills such as writing scripts in HyperTalk the possibility of developing a hypertext system to assist their work.

7.5 Summary

The findings from the current research have made a significant contribution to the hypertext-based learning system design. The work has implications for research areas such as designing hypertext for learning, knowledge representations, human computer interface design, assessment of hypertext-based learning and evaluation of hypertext usability. However, as stated in the discussion, the current work has certain limitations. In order to advance our understanding of the effects of visualising link-types on learning with hypertext, the further work discussed in this chapter is needed and the research questions raised by that work merit further investigation.

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Appendix A Instruments Used in Study One

Self-Assessment Form*

NAME: ______________________________ DATE: ________________

Tick one box only for each question below

1 Have you ever used a MAC?

Yes ☐ Go to question 2
No ☐ Go to question 3

2 How would you rate your knowledge of using a Mac?

Comprehensive ☐ Reasonable ☐ Patchy ☐ Poor ☐

3 Have you ever heard of hypertext?

Yes ☐ Go to question 4
No ☐ Go to question 5

4 How would you rate your knowledge of hypertext?

Comprehensive ☐ Reasonable ☐ Patchy ☐ Poor ☐

5 Have you ever been involved in programming?

Yes ☐ Go to question 6
No ☐ Go to the end

6 How would you rate your knowledge of the use of data structures in programming?

Comprehensive ☐ Reasonable ☐ Patchy ☐ Poor ☐

-- END --

* Only questions 2, 4, and 6 are scorable, each being assigned a range of scores from 1 to 4 corresponding to the scale from "poor" to "comprehensive."

Learner Satisfaction Questionnaire

This form is designed to find out how you enjoy using the hypertext system, and to have your comments on it. Please fill in the information below and add any comments you would like to make. Thank you for your cooperation.

NAME: ______________________ **DATE:** ______________

Tick one box only for each question below

1 How did you enjoy using this hypertext system?

Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

2 How easy did you find it to browse through this hypertext system?

Very easy ☐ Easy ☐ Average ☐ Difficult ☐ Very difficult ☐

3 Did you find the labels on the buttons were helpful? i.e. In finding the information you wanted, were the labels

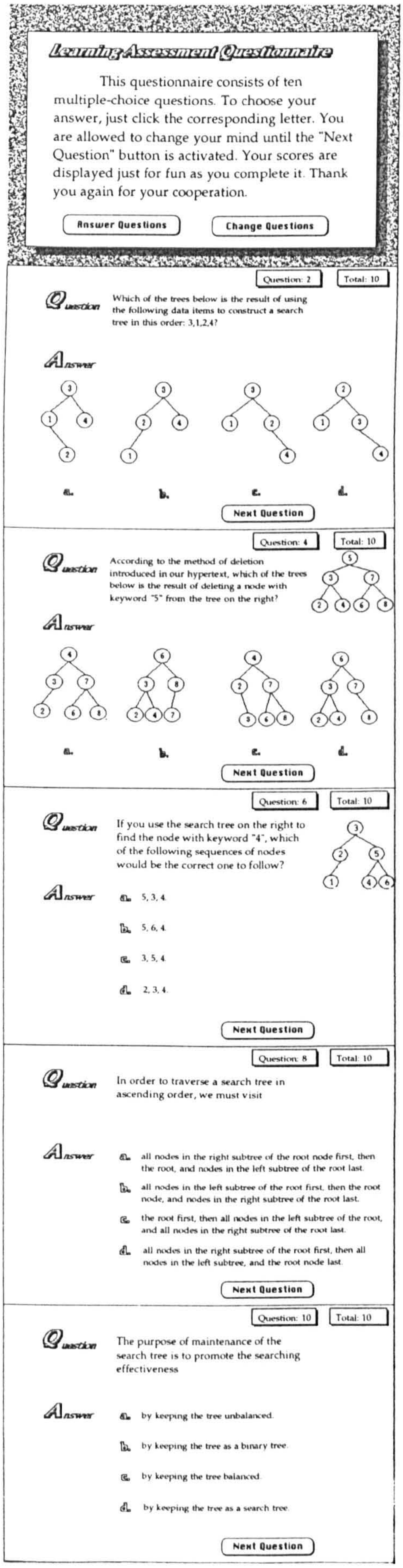
Very helpful ☐ Helpful ☐ Not very helpful ☐ No help at all ☐

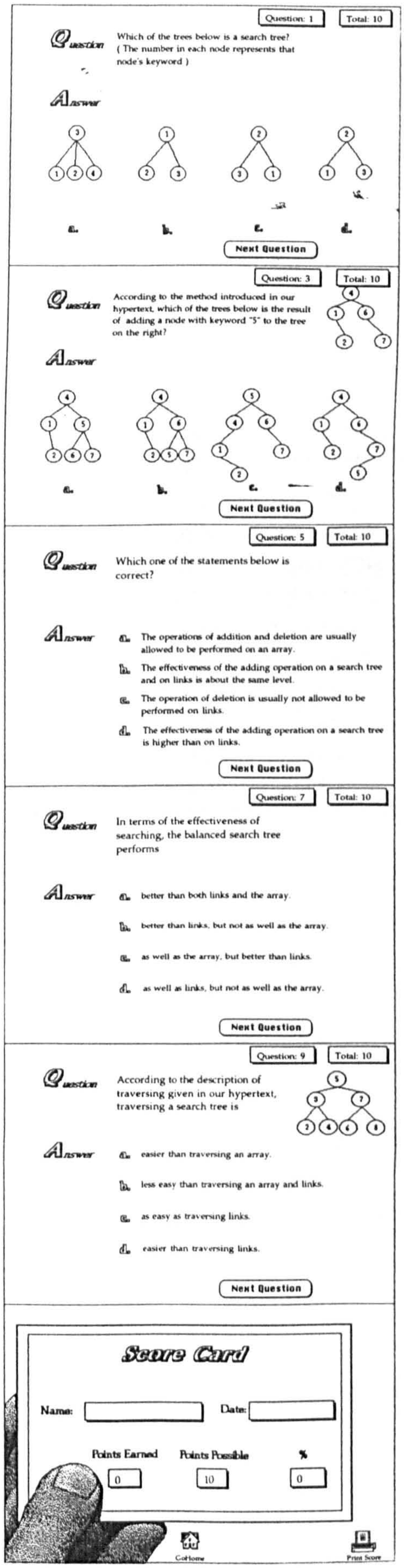
4 What do you think of the way a hotpoint (a textual string with an underline) was represented in the hypertext system?

Very good ☐ Good ☐ Average ☐ Poor ☐ Very poor ☐

5 Please write any other comments you may wish to make about the hypertext system?
Please continue on overleaf if necessary.

Learning Assessment Questionnaire





Appendix B Data and Statistics from Study One

Table B.1.1 Data regarding learning outcomes from the VLTs group and its descriptive statistics.

Subjects	*Self-Assessment*	*Pre-test (%)*	*prior knowledge*	*Post-test (%)*
1	7	40	2.107936962	90
2	7	20	0.612846959	90
3	3	10	-1.576690887	80
4	1	20	-1.550142307	70
5	5	30	0.639395538	70
6	2	10	-1.937189098	60
7	7	10	-0.134698043	60
8	8	20	0.97334517	100
9	10	30	2.441886593	70
10	2	10	-1.937189098	90
Mean	5.2	20	-0.036049821	78
Median	6	20	0.239074458	75
Mode	7	10	-1.937189098	90
Standard Deviation	3.047767854	10.54092553	1.6511768	13.98411798
Variance	9.288888889	111.1111111	2.726384826	195.5555556
Kurtosis	-1.384546894	-0.45	-1.483204324	-1.378855519
Skewness	-0.001177425	0.711512474	0.179205393	0.134080677
Range	9	30	4.379075691	40
Minimum	1	10	-1.937189098	60
Maximum	10	40	2.441886593	100
Sum	52	200	-0.360498211	780

Table B.1.2 Data regarding learning outcomes from the NoVLTs group and its descriptive statistics.

Subjects	*Self-Assessment*	*Pre-test (%)*	*prior knowledge*	*Post-test (%)*
1	3	0	-2.324235889	50
2	6	10	-0.495196254	40
3	3	0	-2.324235889	60
4	10	10	0.94679659	50
5	3	20	-0.829145885	70
6	3	20	-0.829145885	20
7	9	20	1.333843381	90
8	6	40	1.747438751	90
9	4	50	1.773987331	50
10	7	30	1.36039196	90
Mean	5.4	20	0.036049821	61
Median	5	20	0.225800168	55
Mode	3	20	-2.324235889	50
Standard Deviation	2.633122354	16.32993162	1.603403867	23.78141198
Variance	6.933333333	266.6666667	2.570903959	565.5555556
Kurtosis	-0.892923183	-0.287946429	-1.447526333	-0.79609962
Skewness	0.688346289	0.574099158	-0.411646029	-0.085503704
Range	7	50	4.098223219	70
Minimum	3	0	-2.324235889	20
Maximum	10	50	1.773987331	90
Sum	54	200	0.360498211	610

In Table B.1.1 and B.1.2, *Prior knowledge* is the equally weighted sum of self-assessment and pre-test scores. It is calculated in the following formula:

$$<\textit{Prior knowledge}>=(<\textit{Self-Assessment}>-\bar{s})/S_S+(<\textit{Pre-test}>-\bar{p})/S_P$$

$\bar{s}$: mean of assessment scores for all subjects, $\bar{s}=5.3$;

S_S: standard deviation of assessment scores for all subjects, $S_S=2.77393887$;

$\bar{p}$: mean of pre-test scores for all subjects, $\bar{p}=20$;

S_P: standard deviation of pre-test scores for all subjects, $S_P=13.37712108$.

Table B.2.1 The matrix of Pearson's *r* between four data sets (Self-Assessment, Pre-test, Prior knowledge, Post-test) for the VLTs group.

	Self-Assessment	*Pre-test (%)*	*Prior knowledge*	*Post-test (%)*
Self-Assessment	1			
Pre-test (%)	0.518785848	1		
Prior knowledge	0.912990402	0.822431213	1	
Post-test (%)	0.218987746	0.226133508	0.253633735	1

Table B.2.2 The matrix of Pearson's *r* between four data sets (Self-Assessment, Pre-test, Prior knowledge, Post-test) for the NoVLTs group.

	Self-Assessment	*Pre-test (%)*	*Prior knowledge*	*Post-test (%)*
Self-Assessment	1			
Pre-test (%)	0.077521709	1		
Prior knowledge	0.651033374	0.807234092	1	
Post-test (%)	0.401011893	0.314722776	0.477015357	1

The critical significance value of r ($df=8, p<.05$) for both groups is: *0.632* (two-tail test) or *0.549* (one-tail test).

```
13-Sep-93 SPSS Release 4.0 for Macintosh                    Page 1

-> DATA LIST FREE /version posttest.
-> BEGIN DATA
-> 1 90
-> 1 90
-> 1 80
-> 1 70
-> 1 70
-> 1 60
-> 1 60
-> 1 100
-> 1 70
-> 1 90
-> 2 50
-> 2 40
-> 2 60
-> 2 50
-> 2 70
-> 2 20
-> 2 90
-> 2 90
-> 2 50
-> 2 90
-> END DATA.
->
-> ANOVA posttest BY version(1,2).

ANOVA problem requires 160 bytes of memory.
```

```
13-Sep-93 SPSS Release 4.0 for Macintosh                    Page 2

     *** ANALYSIS OF VARIANCE ***

        POSTTEST
     by VERSION
                          Sum of          Mean           Sig
Source of Variation      Squares   DF    Square     F    of F

Main Effects            1445.000    1  1445.000  3.797  .067
  VERSION               1445.000    1  1445.000  3.797  .067

Explained               1445.000    1  1445.000  3.797  .067

Residual                6850.000   18   380.556

Total                   8295.000   19   436.579
20 cases were processed.
0 cases (.0 pct) were missing.
```

Figure B.1 SPSS screen dump of one-factor ANOVA test results, where the hypertext version is the independent variable while the post-test score is the dependent variable.

```
14-Sep-94 SPSS Release 4.0 for Macintosh                    Page 1

->  DATA LIST FREE /version prior posttest.
->  BEGIN DATA
->  1  2.10793696  90
->  1  0.61284696  90
->  1  -1.5766909  80
->  1  -1.5501423  70
->  1  0.63939554  70
->  1  -1.9371891  60
->  1  -0.134698   60
->  1  0.97334517  100
->  1  2.44188659  70
->  1  -1.9371891  90
->  2  -2.3242359  50
->  2  -0.4951963  40
->  2  -2.3242359  60
->  2  0.94679659  50
->  2  -0.8291459  70
->  2  -0.8291459  20
->  2  1.33384338  90
->  2  1.74743875  90
->  2  1.77398733  50
->  2  1.36039196  90
->  END DATA.
->
->  ANOVA posttest BY version(1,2) WITH prior.

ANOVA problem requires 256 bytes of memory.

14-Sep-94 SPSS Release 4.0 for Macintosh                    Page 2

        * * * A N A L Y S I S   O F   V A R I A N C E * * *

          POSTTEST
        by  VERSION
        with PRIOR
                          Sum of              Mean          Sig
Source of Variation       Squares     DF     Square      F   of F

Covariates                926.985      1    926.985   2.686  .120
  PRIOR                   926.985      1    926.985   2.686  .120

Main Effects             1500.355      1   1500.355   4.347  .052
  VERSION                1500.355      1   1500.355   4.347  .052

Explained                2427.339      2   1213.670   3.516  .053

Residual                 5867.661     17    345.157

Total                    8295.000     19    436.579
20 cases were processed.
0 cases (.0 pct) were missing.
```

Figure B.2 SPSS screen dump of ANCOVA test results, where the hypertext version is the independent variable, prior knowledge is utilised as the covariate, and the post-test score is the dependent variable.

Table B.3.1 Data regarding learning processes from the VLTs group and its descriptive statistics.

Subjects	*Time(min)*	*Cards browsed*	*Different cards browsed*	*Associative links activated*	*Referential links activated*
1	14	66	22	6	6
2	20	93	30	25	10
3	31	124	25	26	4
4	24	123	31	30	24
5	19	73	29	25	10
6	27	87	26	26	2
7	22	79	26	23	12
8			the data was lost		
9	16	52	28	19	6
10	26	107	32	46	18
Mean	22.11	89.33	27.67	25.11	10.22
Median	22	87	28	25	10
Mode	#N/A	#N/A	26	25	6
Standard Deviation	5.46	24.94	3.20	10.42	7.03
Variance	29.86	622.25	10.25	108.61	49.44
Kurtosis	-0.70	-1.01	-0.48	2.83	0.51
Skewness	0.08	0.16	-0.38	0.29	0.99
Range	17	72	10	40	22
Minimum	14	52	22	6	2
Maximum	31	124	32	46	24
Sum	199	804	249	226	92

Table B.3.2 Data regarding learning processes from the NoVLTs group and its descriptive statistics.

Subjects	*Time(min)*	*Cards browsed*	*Different cards browsed*	*Associative links activated*	*Referential links activated*
1	14	47	21	16	0
2	30	100	27	44	12
3	30	56	27	24	6
4	22	84	23	28	2
5	27	151	31	74	14
6	22	54	20	20	2
7	19	90	30	34	16
8	22	79	29	26	18
9	10	80	29	29	18
10	19	75	29	23	8
Mean	21.5	81.6	26.6	31.8	9.6
Median	22	79.5	28	27	10
Mode	22	#N/A	29	#N/A	2
Standard Deviation	6.47	29.62	3.89	16.73	6.92
Variance	41.83	877.6	15.16	279.73	47.82
Kurtosis	-0.34	2.96	-0.86	4.83	-1.73
Skewness	-0.30	1.40	-0.81	2.08	-0.11
Range	20	104	11	58	18
Minimum	10	47	20	16	0
Maximum	30	151	31	74	18
Sum	215	816	266	318	96

Table B.4.1 Data regarding prior knowledge and improvement scores from the VLTs group.

Subjects	*prior knowledge*	*Improvment*
1	(high)2.107936959	5
2	(high)0.612846958	7
3	(low)-1.576690886	7
4	(low)-1.550142307	5
5	(high)0.639395537	4
6	(low)-1.937189096	5
7	(low)-0.134698041	5
8	(high)0.973345169	8
9	(high)2.441886592	4
10	(low)-1.937189096	8

Table B.4.2 Data regarding prior knowledge and improvement scores from the NoVLTs group.

Subjects	*prior knowledge*	*Improvement*
1	(low)-2.324235886	5
2	(low)-0.495196252	3
3	(low)-2.324235886	6
4	(high)0.946796591	4
5	(low)-0.829145885	5
6	(low)-0.829145885	0
7	(high)1.333843380	7
8	(high)1.747438748	5
9	(high)1.773987327	0
10	(high)1.360391959	6

All subjects are median-split according to prior knowledge scores. The median of prior knowledge scores is *0.239074458*.

```
14-Sep-94 SPSS Release 4.0 for Macintosh                    Page 1

-> DATA LIST FREE /version prior improv.
-> BEGIN DATA
-> 1 3  5
-> 1 3  7
-> 1 4  7
-> 1 4  5
-> 1 3  4
-> 1 4  5
-> 1 4  5
-> 1 3  8
-> 1 3  4
-> 1 4  8
-> 2 4  5
-> 2 4  3
-> 2 4  6
-> 2 3  4
-> 2 4  5
-> 2 4  0
-> 2 3  7
-> 2 3  5
-> 2 3  0
-> 2 3  6
-> END DATA.
->
-> ANOVA improv BY version(1,2) prior(3,4) /STATISTICS MEAN.

ANOVA problem requires 392 bytes of memory.
```

```
14-Sep-94 SPSS Release 4.0 for Macintosh                    Page 3

        *** ANALYSIS OF VARIANCE ***

          IMPROV
        by VERSION
           PRIOR
```

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	14.500	2	7.250	1.585	.236
VERSION	14.450	1	14.450	3.158	.095
PRIOR	.050	1	.050	.011	.918
2-Way Interactions	1.250	1	1.250	.273	.608
VERSION PRIOR	1.250	1	1.250	.273	.608
Explained	15.750	3	5.250	1.148	.360
Residual	73.200	16	4.575		
Total	88.950	19	4.682		

20 cases were processed.
0 cases (.0 pct) were missing.

Figure B.3 SPSS screen dump of two-factor ANOVA test results, where hypertext versions and prior knowledge are two independent variables while the improvement score is the dependent variable.

Appendix C Instruments Used in Study Two

Self-Assessment Form*

This questionnaire is designed to find out your background knowledge to use the experiment system. Please tick one box only for each question below.

The information provided by you will not be used for any purposes other than research, and the confidentiality of such information will be preserved.

Thank you for your cooperation.

NAME: ______________________ **DATE:** ______________

1. Have you ever used a Macintosh computer?
   Yes ☐ Go to question 2
   No ☐ Go to question 3

2. How would you rate your knowledge of using a Macintosh computer?

   Comprehensive ☐ Reasonable ☐ Patchy ☐ Poor ☐

3. Have you ever heard of hypertext/hypermedia?
   Yes ☐ Go to question 4
   No ☐ Go to question 6

4. Have you ever used a hypertext/hypermedia system?
   Yes ☐ Go to question 5
   No ☐ Go to question 6

5. How would you rate your knowledge of hypertext/hypermedia systems?

   Comprehensive ☐ Reasonable ☐ Patchy ☐ Poor ☐

6. Have you ever been involved in programming on any computers?
   Yes ☐ Go to question 7
   No ☐ Go to END

7. Have you ever read any materials on data structures?
   Yes ☐ Go to question 8
   No ☐ Go to END

8. How would you rate your knowledge of the use of data structures in programming?

   Comprehensive ☐ Reasonable ☐ Patchy ☐ Poor ☐

---

* Only questions 2, 5, and 8 are scorable, each being assigned a range of scores from 1 to 4 corresponding to the scale from "poor" to "comprehensive."

Learning Assessment Questionnaire

This questionnaire consists of two parts. There are ten questions in each part. Choose the most appropriate answer for each question. On the answer sheet provided, fill in the circle with the same letter of the answer chosen.

The result of this assessment will not be used for any purposes other than research, and the confidentiality of the result will be preserved.

Thank you for your cooperation.

PART ONE: Structural Knowledge

1. Dynamic lists ------ trees*.

   (a) represent
   (b) are a type of
   (c) can be represented by
   (d) comprise

2. Static lists differ from dynamic lists in that

   (a) static lists usually consist of fewer items than dynamic lists.
   (b) items in static lists must all be of the same type whereas items in dynamic lists can have different types.
   (c) static lists consist of a fixed number of items whereas dynamic lists can contain various number of items.
   (d) the insertion operation can be performed on static lists but cannot be carried out on dynamic lists.

3. In terms of efficiency of searching operation, trees are normally

   (a) better than both links and arrays.
   (b) better than links, but not as good as arrays.
   (c) as good as arrays, but better than links.
   (d) as good as links, but not as good as arrays.

4. Inserting an item in a tree ------ building a tree.

   (a) is a type of
   (b) consists of
   (c) is a basic part of
   (d) is similar to

* The term of "tree"/"trees" used in this questionnaire particularly means "search tree"/"search trees".

5. Which one of the statements below do you consider to be correct?

   (a) Searching links includes the traversing operation.
   (b) The efficiency of searching links is examined by working out its complexity.
   (c) Searching links is one of operations performed on lists.
   (d) Searching links is same as searching trees.

<u>In the following five questions, a related pair of words or phrases is followed by three pairs of words or phrases. Select the pair that best expresses a relationship similar to that expressed in the original pair.</u>

EXAMPLE:
BAMBOO : SHOOT ::

(a) oak : tree
(b) bean : sprout
(c) pepper : corn

THE ANSWER IS: (b).

6. BINARY SEARCHING : ARRAY ::

   (a) information : list
   (b) linear searching : links
   (c) memory : Tree

7. STATIC LIST : DYNAMIC LIST ::

   (a) trees : links
   (b) arrays : trees
   (c) links : arrays

8. SEARCHING : ARRAY ::

   (a) static list : array
   (b) traversing : tree
   (c) searching : complexity of searching

9. INSERTING IN TREES : BUILDING TREES ::

   (a) complexity of searching trees : complexity of searching links
   (b) array : tree
   (c) searching links : deleting links

10. QUERY : SEARCHING ::

    (a) printing : traversing
    (b) index : keyword
    (c) balanced tree : searching

PART TWO: Non-structural Knowledge

1. Which one of statements below is not correct?

   (a) An array consists of a fixed number of elements.
   (b) Items of an array can have different types.
   (c) Items of an array are placed contiguously in memory.
   (d) Each element is identified by a single index in a one-dimensional array.

2. How many comparisons are required to find the item "Nottingham" in the array on the right?

   (a) one
   (b) two
   (c) three
   (d) four

Index	LOCATION	Tel. No.
1	Belfast	0232 245025
2	Birmingham	021 426 1661
3	Bristol	0272 299641
4	Cambridge	0223 64721
5	Cardiff	0222 397911
6	East Grinstead	0342 27821
7	Edinburgh	031 226 3851
8	Leeds	0532 444431
9	London	071 794 0575
10	Manchester	061 861 9823
11	Newcastle	091 284 1611
12	Nottingham	0602 473072
13	Oxford	0865 730731

3. Which one of the statements below is not correct?

   (a) Links can consist of various number of items of data.
   (b) The items of links are necessarily held contiguously in memory.
   (c) Each item in links must have an extra field which is used to reference the next item in the links.
   (d) All items in links are connected one by one like a chain.

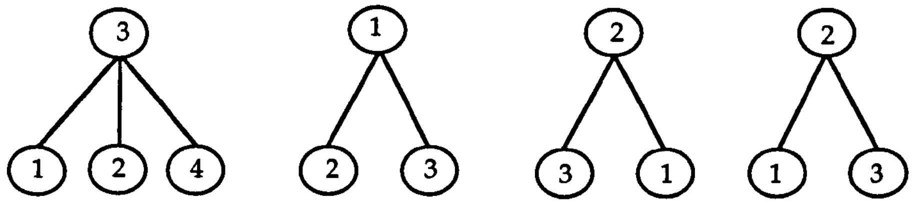
4. To find an item in a linked list,

   (a) the binary searching technique can be used.
   (b) only the linear searching technique can be used.
   (c) either the binary or linear searching technique can be used.
   (d) neither the binary nor linear searching technique can be used.

5. For a linked list of **n** items, the complexity of searching operation is

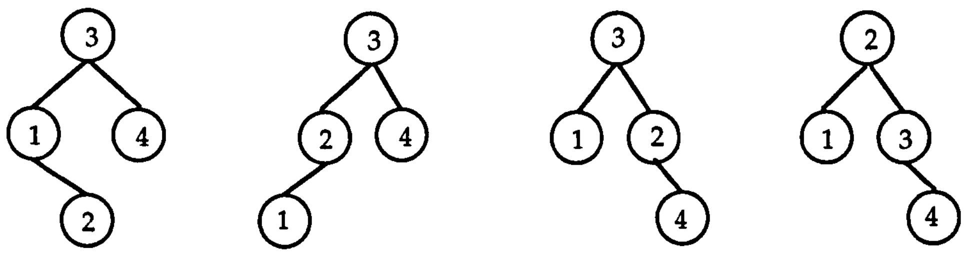
   (a) n
   (b) $\log_2 n$
   (c) n^2
   (d) 2^n

6. Which one of the following figures represents a tree (The number in each node represents that node's keyword)?



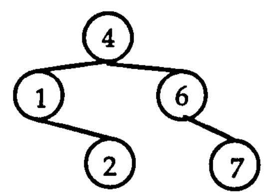
(a) (b) (c) (d)

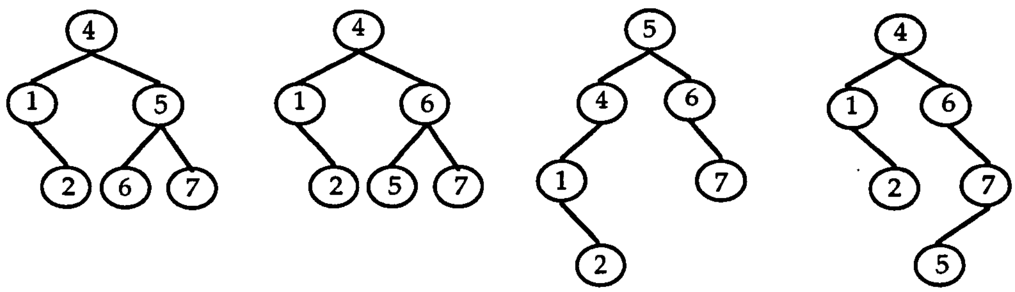
7. Which one of the following trees is the result of building in this order: 3,1,2,4?



(a) (b) (c) (d)

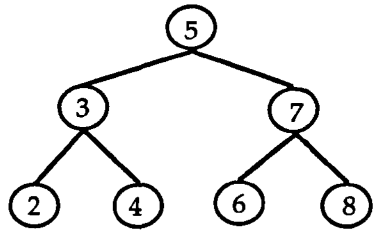
8. Which one of the following trees is the result of inserting a node with keyword "5" in the tree on the right?

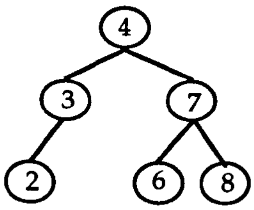




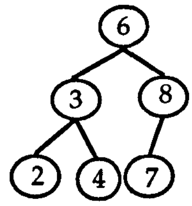
(a) (b) (c) (d)

9. Which one of the following trees is the result of deleting a node with keyword "5" from the tree on the right?

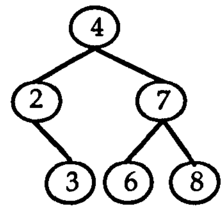




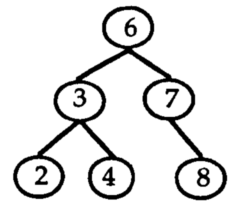
(a)



(b)

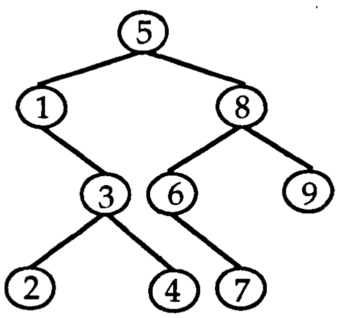


(c)



(d)

10. If the tree on the right is used to find the node with keyword "4", which one of the following sequences represents the correct sequence of nodes that are compared with the node "4"?



(a) 3,1,5,2
(b) 1,3,2
(c) 5,1,3
(d) 2,3,1,5,8

ANSWER KEY

Part one: Structural knowledge

1 c; 2 c; 3 c; 4 c; 5 b; 6 b; 7 a; 8 b; 9 c; 10 a.

Part two: Non-structural knowledge

1 b; 2 c; 3 b; 4 b; 5 a; 6 d; 7 a; 8 b; 9 d; 10 c.

Learner Satisfaction Questionnaire (for the VLTs group)

This questionnaire is designed to elicit your opinion on the usability of the experiment system. Please tick one box only for each question below.

Thank you for your cooperation.

NAME: ____________________________ **DATE:** ________________

1. How did you enjoy using this hypertext system?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

2. How easy did you find it to browse through this hypertext system?

   Very easy ☐ Easy ☐ Average ☐ Difficult ☐ Very difficult ☐

3. How helpful did you find the global structure diagram was?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

4. How helpful did you find the local structure diagram was?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

4'. How helpful did you find the labels attached to lines in the local structure diagram were?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

5. How helpful did you find the "Index" was?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

6. How helpful did you find the "Go recent" was?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

7. How helpful did you find the help balloons were?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

8. What do you think of the way a hotpoint (a interactive textual string with an underline) was represented in the textual area?

   Very good ☐ Good ☐ Average ☐ Poor ☐ Very poor ☐

Learner Satisfaction Questionnaire (for the NoVLTs group)

This questionnaire is designed to elicit your opinion on the usability of the experiment system. Please tick one box only for each question below.

Thank you for your cooperation.

NAME: ____________________________ DATE: ________________

1. How did you enjoy using this hypertext system?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

2. How easy did you find it to browse through this hypertext system?

   Very easy ☐ Easy ☐ Average ☐ Difficult ☐ Very difficult ☐

3. How helpful did you find the global structure diagram was?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

4. How helpful did you find the local structure diagram was?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

5. How helpful did you find the "Index" was?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

6. How helpful did you find the "Go recent" was?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

7. How helpful did you find the help balloons were?

   Very much ☐ Fairly ☐ Not very ☐ Not at all ☐

8. What do you think of the way a hotpoint (a interactive textual string with an underline) was represented in the textual area?

   Very good ☐ Good ☐ Average ☐ Poor ☐ Very poor ☐

Table C.1 Subjects' responses to the satisfaction questionnaire.

Q1	Very much	Fairly	Not very	Not at all
VLTs	7	7	0	0
NoVLTs	6	6	1	0

Q2	Very easy	Easy	Average	Difficult	Very difficult
VLTs	7	6	1	0	0
NoVLTs	5	4	1	3	0

Q3	Very much	Fairly	Not very	Not at all
VLTs	9	4	1	0
NoVLTs	11	1	1	0

Q4	Very much	Fairly	Not very	Not at all
VLTs	11	3	0	0
NoVLTs	7	5	1	0

Q5	Very much	Fairly	Not very	Not at all
VLTs	2	6	4	2
NoVLTs	4	6	2	1

Q6	Very much	Fairly	Not very	Not at all
VLTs	1	2	7	4
NoVLTs	3	1	5	4

Q7	Very much	Fairly	Not very	Not at all
VLTs	2	4	4	4
NoVLTs	2	2	2	7

Q8	Very good	Good	Average	Poor	Very poor
VLTs	5	6	2	1	0
NoVLTs	6	4	3	0	0

Q4′	Very much	Fairly	Not very	Not at all
VLTs	3	10	1	0

Appendix D Data and Statistics from Study Two

Table D.1.1 Data regarding learning outcomes from the VLTs group and its descriptive statistics.

Subjects	*Self-Assessment*	*Part1 of pre-test (%)*	*Part2 of pre-test (%)*	*Total of pre-test (%)*	*Prior knowledge*	*Part1 of post-test (%)*	*Part2 of post-test (%)*	*Total of post-test (%)*
1	12	60	70	65	3.539981539	60	100	80
2	4	20	20	20	-1.440582723	20	50	35
3	6	20	20	20	-0.906549057	50	60	55
4	3	50	60	55	0.504734577	70	90	80
5	3	20	10	15	-2.023647289	30	20	25
6	0	60	20	40	-1.244459121	20	50	35
7	5	60	70	65	1.670863709	50	90	70
8	0	50	10	30	-1.876554588	50	50	50
9	0	30	30	30	-1.876554588	20	50	35
10	3	40	60	50	0.188686844	50	90	70
11	3	50	60	55	0.504734577	40	90	65
12	4	70	60	65	1.403846876	60	90	75
13	5	50	50	50	0.722720509	60	90	75
14	7	40	80	60	1.888849641	80	80	80
Mean	3.928571429	44.28571429	44.28571429	44.28571429	0.075433636	47.14285714	71.42857143	59.28571429
Median	3.5	50	55	50	0.34671071	50	85	67.5
Mode	3	50	60	65	0.504734577	50	90	80
Standard Deviation	3.173551413	16.50840612	24.7181919	18.17195037	1.696907211	18.98524586	24.13332929	19.79288361
Variance	10.07142857	272.5274725	610.989011	330.2197802	2.879494084	360.4395604	582.4175824	391.7582418
Kurtosis	2.278192307	-1.022792309	-1.678865671	-1.420491134	-0.5580818	-0.790793494	-0.506848118	-1.341210635
Skewness	1.069945313	-0.33218658	-0.185544758	-0.393266682	0.43217001	-0.150951622	-0.731001895	-0.544913715
Range	12	50	70	50	5.563628827	60	80	55
Minimum	0	20	10	15	-2.023647289	20	20	25
Maximum	12	70	80	65	3.539981539	80	100	80
Sum	55	620	620	620	1.056070908	660	1000	830

Table D.1.2 Data regarding learning outcomes from the NoVLTs group and its descriptive statistics.

Subjects	*Self-Assessment*	*Part1 of pre-test (%)*	*Part2 of pre-test (%)*	*Total of pre-test (%)*	*Prior knowledge*	*Part1 of post-test (%)*	*Part2 of post-test (%)*	*Total of post-test (%)*
1	11	60	10	35	1.376678307	80	60	70
2	9	50	30	40	1.158692374	80	90	85
3	10	50	70	60	2.68990014	50	70	60
4	8	50	40	45	1.207723275	60	60	60
5	0	40	20	30	-1.876554588	40	20	30
6	0	10	20	15	-2.824697787	60	50	55
7	4	40	50	45	0.139655943	50	90	70
8	10	50	60	55	2.373852407	80	100	90
9	3	70	30	50	0.188686844	70	80	75
10	2	40	40	40	-0.710425455	40	70	55
11	2	10	50	30	-1.342520922	40	60	50
12	0	30	10	20	-2.508650054	20	30	25
13	0	50	40	45	-0.928411388	60	60	60
Mean	4.538461538	42.30769231	36.15384615	39.23076923	-0.081236223	56.15384615	64.61538462	60.38461538
Median	3	50	40	40	0.139655943	60	60	60
Mode	0	50	40	45	#N/A	80	60	60
Standard Deviation	4.389673196	17.39436985	18.50155919	13.04577739	1.791162896	18.50155919	22.95480509	18.75961292
Variance	19.26923077	302.5641026	342.3076923	170.1923077	3.208264521	342.3076923	526.9230769	351.9230769
Kurtosis	-1.755606044	0.448910971	-0.650574422	-0.304755106	-1.115431135	-0.487647336	-0.00355131	0.116639656
Skewness	0.36727793	-0.754056222	0.204272876	-0.367320975	-0.005949366	-0.262242205	-0.430146179	-0.417669621
Range	11	60	60	45	5.514597927	60	80	65
Minimum	0	10	10	15	-2.824697787	20	20	25
Maximum	11	70	70	60	2.68990014	80	100	90
Sum	59	550	470	510	-1.056070904	730	840	785

In Table D.1.1 and D.1.2, *Prior knowledge* is the equally weighted sum of self-assessment and pre-test scores. It is calculated in the following formula:

<Prior knowledge>=(<Self-Assessment>- $\bar{s}$)/S_s+(*<Pre-test>*-$\bar{p}$)/S_p

$\bar{s}$: mean of assessment scores for all subjects, $\bar{s}=4.2$;

S_s: standard deviation of assessment scores for all subjects, S_s=3.745082246;

$\bar{p}$: mean of pre-test scores for all subjects, $\bar{p}=41.9$;

S_p: standard deviation of pre-test scores for all subjects, $S_p=15.82039507$.

Table D.2.1 The matrix of Pearson's *r* between eight data sets (Self-Assessment, Part 1 of pre-test, Part 2 of pre-test, Total of pre-test, Prior knowledge, Part 1 of post-test, Part 2 of post-test, Total of post-test) for the VLTs group.

	Self-Assessment	*Part1 of pre-test (%)*	*Part2 of pre-test (%)*	*Total of pre-test (%)*	*Prior knowledge*	*Part1 of post-test (%)*	*Part2 of post-test (%)*	*Total of post-test (%)*
Self-Assessment	1							
Part1 of pre-test (%)	0.109071496	1						
Part2 of pre-test (%)	0.56314784	0.535907506	1					
Total of pre-test (%)	0.432551064	0.818708782	0.923543428	1				
Prior knowledge	0.792169079	0.608653515	0.906370352	0.892907339	1			
Part1 of post-test (%)	0.545340851	0.38568249	0.700159314	0.651379599	0.713249623	1		
Part2 of post-test (%)	0.523707381	0.639917828	0.891599941	0.897062813	0.86875001	0.681151133	1	
Total of post-test (%)	0.580820695	0.575096207	0.879355741	0.85929152	0.871703442	0.894859262	0.93632519	1

The critical significance value of *r* (*df=12, p<.05*) is: *0.532* (two-tail test) or *0.458* (one-tail test).

Table D.2.2 The matrix of Pearson's *r* between four data sets (Self-Assessment, Part 1 of pre-test, Part 2 of pre-test, Total of pre-test, Prior knowledge, Part 1 of post-test, Part 2 of post-test, Total of post-test) for the NoVLTs group.

	Self-Assessment	*Part1 of pre-test (%)*	*Part2 of pre-test (%)*	*Total of pre-test (%)*	*Prior knowledge*	*Part1 of post-test (%)*	*Part2 of post-test (%)*	*Total of post-test (%)*
Self-Assessment	1							
Part1 of pre-test (%)	0.528062294	1						
Part2 of pre-test (%)	0.345707653	0.055772024	1					
Total of pre-test (%)	0.597183326	0.706214689	0.746282794	1				
Prior knowledge	0.92932059	0.670685908	0.569801705	0.851171151	1			
Part1 of post-test (%)	0.653529536	0.547760947	0.074906367	0.418290178	0.62023522	1		
Part2 of post-test (%)	0.577001431	0.388515597	0.594688698	0.680705012	0.690966948	0.633932114	1	
Total of post-test (%)	0.675287675	0.507812487	0.400777132	0.622733301	0.728595264	0.880970931	0.924420396	1

The critical significance value of *r* (*df=11, p<.05*) is: *0.553* (two-tail test) or *0.476* (one-tail test).

```
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-> DATA LIST FREE /version prior part1 part2.
-> BEGIN DATA
-> 1  3.53998154  60  100
-> 1  -1.4405827  20  50
-> 1  -0.9065491  50  60
-> 1  0.50473458  70  90
-> 1  -2.0236473  30  20
-> 1  -1.2444591  20  50
-> 1  1.67086371  50  90
-> 1  -1.8765546  50  50
-> 1  -1.8765546  20  50
-> 1  0.18868685  50  90
-> 1  0.50473458  40  90
-> 1  1.40384688  60  90
-> 1  0.72272051  60  90
-> 1  1.88884964  80  80
-> 2  1.3766783  80  60
-> 2  1.15869237  80  90
-> 2  2.68990014  50  70
-> 2  1.20772327  60  60
-> 2  -1.8765546  40  20
-> 2  -2.8246978  60  50
-> 2  0.13965594  50  90
-> 2  2.37385241  80  100
-> 2  0.18868685  70  80
-> 2  -0.7104255  40  70
-> 2  -1.3425209  40  60
-> 2  -2.5086501  20  30
-> 2  -0.9284114  60  60
-> END DATA.
->
-> ANOVA part1 part2 BY version (1,2) WITH prior.

ANOVA problem requires 344 bytes of memory.

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          * * * A N A L Y S I S   O F   V A R I A N C E * * *

           PART1
           by  VERSION
           with PRIOR
                          Sum of                Mean            Sig
Source of Variation       Squares      DF      Square       F   of F

Covariates               3773.230       1    3773.230  18.570  .000
  PRIOR                  3773.230       1    3773.230  18.570  .000

Main Effects              691.059       1     691.059   3.401  .078
  VERSION                 691.059       1     691.059   3.401  .078

Explained                4464.290       2    2232.145  10.986  .000

Residual                 4876.451      24     203.185

Total                    9340.741      26     359.259
27 cases were processed.
0 cases (.0 pct) were missing.

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          * * * A N A L Y S I S   O F   V A R I A N C E * * *

           PART2
           by  VERSION
           with PRIOR
                          Sum of                Mean            Sig
Source of Variation       Squares      DF      Square       F   of F

Covariates               8634.825       1    8634.825  38.421  .000
  PRIOR                  8634.825       1    8634.825  38.421  .000

Main Effects              178.775       1     178.775    .795  .381
  VERSION                 178.775       1     178.775    .795  .381

Explained                8813.600       2    4406.800  19.608  .000

Residual                 5393.807      24     224.742

Total                   14207.407      26     546.439
27 cases were processed.
0 cases (.0 pct) were missing.
```

Figure D.1 SPSS screen dump of ANCOVA test results, where the hypertext version is the independent variable, the prior knowledge score is used as the covariate, and the two pasts of post-test are the dependent variables.

Table D.3.1 Data regarding learning processes from the VLTs group and its descriptive statistics.

Subjects	*Time (min)*	*Cards browsed*	*Different cards browsed*	*Diagram mode*	*Index mode*	*Back mode*	*Recent mode*
1	33	40	22	32	5	2	0
2	34	36	22	22	13	0	0
3	46	47	22	35	4	3	4
4	54	38	22	5	30	2	0
5	39	50	22	49	0	0	0
6	55	34	22	26	0	3	4
7	38	31	22	21	4	4	1
8	32	90	22	45	10	33	1
9	38	40	22	38	0	1	0
10	30	51	22	47	0	3	0
11	45	47	22	0	43	3	0
12	24	30	22	27	2	0	0
13	23	56	22	52	3	0	0
14	27	48	22	45	0	0	2
Mean	37	45.57142857	22	31.71428571	8.142857143	3.857142857	0.857142857
Median	36	43.5	22	33.5	3.5	2	0
Mode	38	40	22	45	0	0	0
Standard Deviation	10.10711859	15.04206556	0	16.00686666	12.88921519	8.51114331	1.460091823
Variance	102.1538462	226.2637363	0	256.2197802	166.1318681	72.43956044	2.131868132
Kurtosis	-0.563029294	5.827828704	#DIV/0!	-0.258471528	3.829325088	13.00910948	1.590097489
Skewness	0.477714119	2.083695158	#DIV/0!	-0.685835895	2.081883192	3.555376103	1.669856848
Range	32	60	0	52	43	33	4
Minimum	23	30	22	0	0	0	0
Maximum	55	90	22	52	43	33	4
Sum	518	638	308	444	114	54	12

Table D.3.2 Data regarding learning processes from the NoVLTs group and its descriptive statistics.

Subjects	*Time(min)*	*Cards*	*Different cards browsed*	*Diagram*	*Index*	*Back*	*Recent*
1	54	83	22	63	13	6	0
2	36	44	22	37	2	1	3
3	10	29	22	19	9	0	0
4	29	46	22	45	0	0	0
5	35	38	22	37	0	0	0
6	46	35	22	34	0	0	0
7	23	41	22	38	1	1	0
8	34	35	22	31	3	0	0
9	31	62	22	44	4	12	1
10	48	66	22	65	0	0	0
11	39	31	22	20	10	0	0
12	39	44	22	32	5	6	0
13	34	39	22	35	3	0	0
Mean	35.23076923	45.61538462	22	38.46153846	3.846153846	2	0.307692308
Median	35	41	22	37	3	0	0
Mode	34	44	22	37	0	0	0
Standard Deviation	11.20382261	15.61270029	0	13.64194136	4.298180891	3.719318934	0.854850414
Variance	125.525641	243.7564103	0	186.1025641	18.47435897	13.83333333	0.730769231
Kurtosis	1.270553843	1.528350564	#DIV/0!	0.556809324	0.159488691	3.740461078	9.72299169
Skewness	-0.571566426	1.402054715	#DIV/0!	0.753747906	1.091890385	2.032842233	3.078408694
Range	44	54	0	46	13	12	3
Minimum	10	29	22	19	0	0	0
Maximum	54	83	22	65	13	12	3
Sum	458	593	286	500	50	26	4

Appendix E Instruments Used in Study Three

Self-Assessment Form

same as the form used in Study Two (see the Self-Assessment Form in Appendix C)

Learning Assessment Questionnaire

This questionnaire consists of two parts. There are ten questions in Part One, and fifteen questions in Part Two. Choose the most appropriate answer for each question. On the answer sheet provided, fill in the circle with the same letter of the answer chosen.

The result of this assessment will not be used for any purposes other than research, and the confidentiality of the result will be preserved.

Thank you for your cooperation.

PART ONE: Structural Knowledge

same as that used in Study Two (see the Learning Assessment Questionnaire in Appendix C)

PART TWO: Non-structural Knowledge

1. Which one of statements below is not correct?

   (a) An array consists of a fixed number of elements.
   (b) Items of an array can have different types.
   (c) Items of an array are placed contiguously in memory.
   (d) Each element is identified by a single index in a one-dimensional array.

2. How many comparisons are required to find the item "Nottingham" in the array on the right?

   (a) one
   (b) two
   (c) three
   (d) four

Index	LOCATION	Tel. No.
1	Belfast	0232 245025
2	Birmingham	021 426 1661
3	Bristol	0272 299641
4	Cambridge	0223 64721
5	Cardiff	0222 397911
6	East Grinstead	0342 27821
7	Edinburgh	031 226 3851
8	Leeds	0532 444431
9	London	071 794 0575
10	Manchester	061 861 9823
11	Newcastle	091 284 1611
12	Nottingham	0602 473072
13	Oxford	0865 730731

3. In the case that a list is represented by an array, how many kinds of traversing are facilitated?

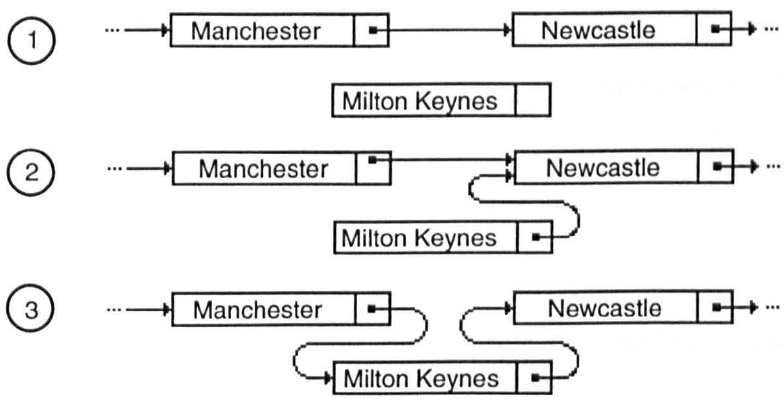
    (a) one
    (b) two
    (c) three
    (d) four

4. Which one of the statements below is not correct?

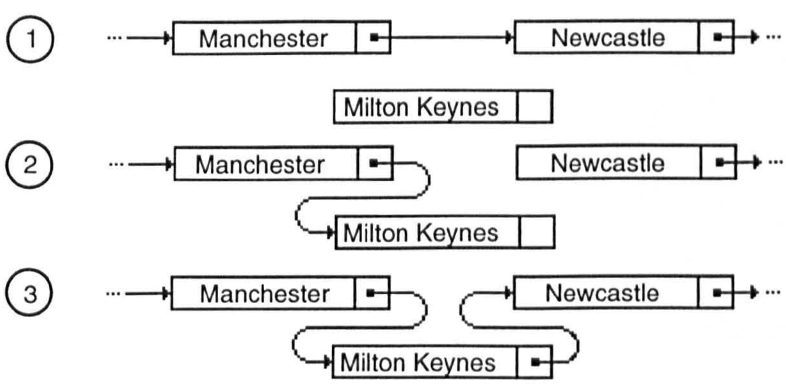
    (a) Links can consist of various number of items of data.
    (b) The items of links are necessarily held contiguously in memory.
    (c) Each item in links must have an extra field which is used to reference the next item in the links.
    (d) All items in links are connected one by one like a chain.

5. According to the method introduced in our hypertext, which one of the illustrations shown below correctly illustrates inserting an item in links.

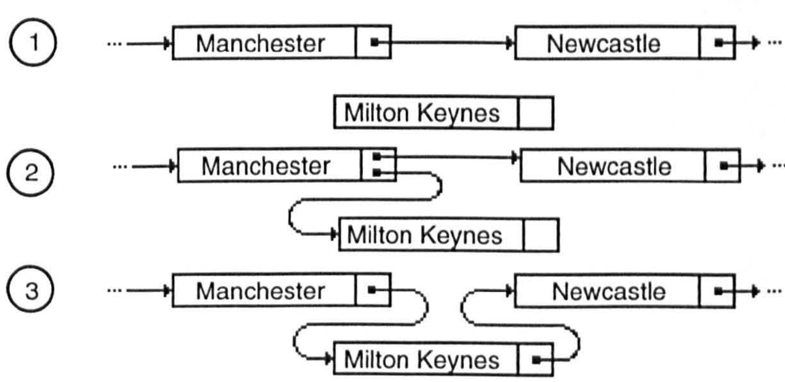
(a)



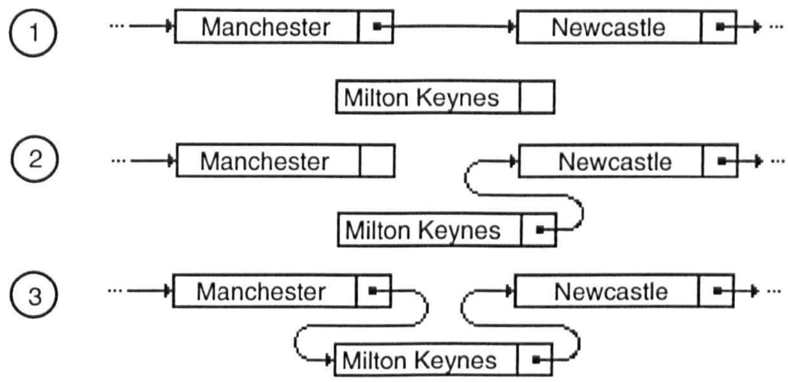
(b)



(c)



(d)



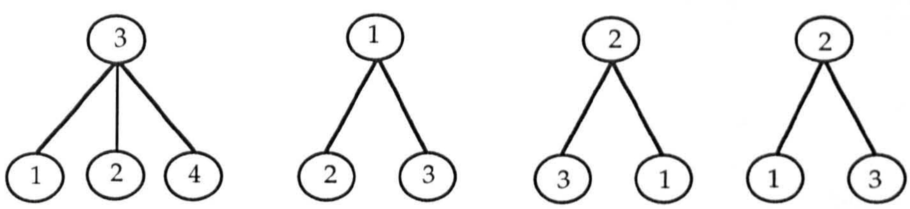
6. To find an item in a linked list,

   (a) the binary searching technique can be used.
   (b) only the linear searching technique can be used.
   (c) either the binary or linear searching technique can be used.
   (d) neither the binary nor linear searching technique can be used.

7. For a linked list of **n** items, the complexity of searching operation is

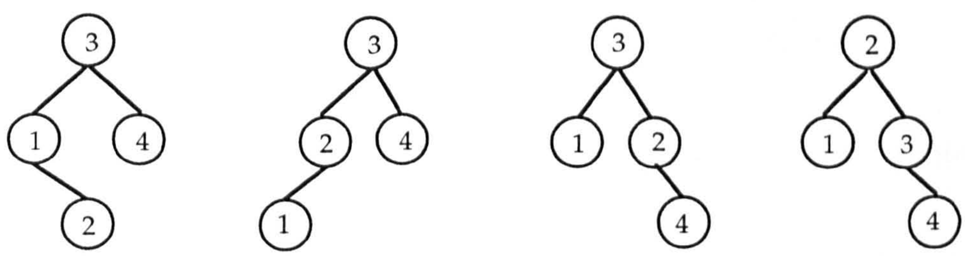
   (a) $\mathbf{n}$
   (b) $\log_2 \mathbf{n}$
   (c) $\mathbf{n}^2$
   (d) $2^{\mathbf{n}}$

8. Which one of the following figures represents a tree (The number in each node represents that node's keyword)?



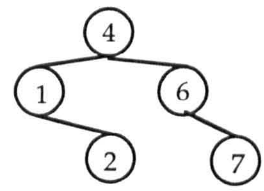
(a) (b) (c) (d)

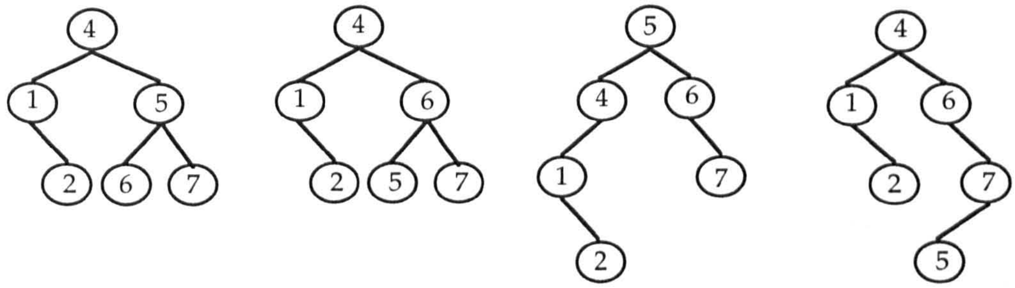
9. Which one of the following trees is the result of building in this order: 3,1,2,4?



(a) (b) (c) (d)

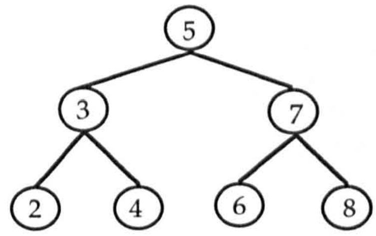
10. Which one of the following trees is the result of inserting a node with keyword "5" in the tree on the right?

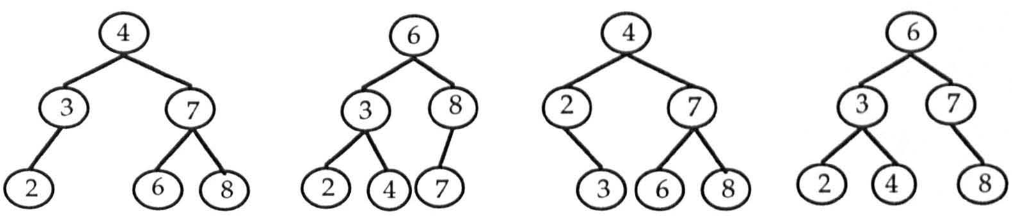




(a) (b) (c) (d)

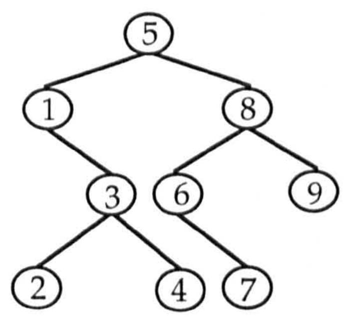
11. Which one of the following trees is the result of deleting a node with keyword "5" from the tree on the right?





(a) (b) (c) (d)

12. If the tree on the right is used to find the node with keyword "4", which one of the following sequences represents the correct sequence of nodes that are compared with the node "4"?



(a) 3,1,5,2
(b) 1,3,2
(c) 5,1,3
(d) 2,3,1,5,8

13. In order to traverse a tree in ascending order, according to the method introduced in our hypertext we must visit

(a) all nodes in the right subtree of the root node first, then the root, and nodes in the left subtree of the root last.
(b) all nodes in the left subtree of the root first, then the root node, and nodes in the right subtree of the root last.

(c) the root first, then all nodes in the left subtree of the root, and all nodes in the right subtree of the root last.
(d) all nodes in the right subtree of the root first, then all nodes in the left subtree, and the root node last.

14. The purpose of maintenance of the tree is to promote the efficiency of searching

(a) by keeping the tree unbalanced.
(b) by keeping the tree as a binary tree.
(c) by keeping the tree balanced.
(d) by keeping the tree as a subtree.

15. According to the method introduced in our hypertext, the maximum number of comparisons required to find any item in a balanced tree of 500 nodes is

(a) about 9.
(b) about 90.
(c) about 500.
(d) about 50.

ANSWER KEY

Part one: Structural knowledge

1 c; 2 c; 3 c; 4 c; 5 b; 6 b; 7 a; 8 b; 9 c; 10 a.

Part two: Non-structural knowledge

1 b; 2 c; 3 b; 4 b; 5 a; 6 b; 7 a; 8 d; 9 a; 10 b; 11 d; 12 c; 13 b; 14 c; 15 a.

Learner Satisfaction Questionnaire (for the VLTs group)

same as the questionnaire used in Study Two (see the Learner Satisfaction Questionnaire in Appendix C)

Learner Satisfaction Questionnaire (for the NoVLTs group)

same as the questionnaire used in Study Two (see the Learner Satisfaction Questionnaire in Appendix C)

Table E.1 Subjects' responses to the satisfaction questionnaire.

Q1	Very much	Fairly	Not very	Not at all
VLTs	6	6	0	0
NoVLTs	6	6	0	0

Q2	Very easy	Easy	Average	Difficult	Very difficult
VLTs	4	7	1	0	0
NoVLTs	7	2	3	0	0

Q3	Very much	Fairly	Not very	Not at all
VLTs	6	3	3	0
NoVLTs	7	4	0	0

Q4	Very much	Fairly	Not very	Not at all
VLTs	10	2	0	0
NoVLTs	7	4	1	0

Q5	Very much	Fairly	Not very	Not at all
VLTs	0	6	4	2
NoVLTs	6	2	4	0

Q6	Very much	Fairly	Not very	Not at all
VLTs	2	4	4	2
NoVLTs	3	3	2	4

Q7	Very much	Fairly	Not very	Not at all
VLTs	1	6	1	4
NoVLTs	4	5	2	1

Q8	Very good	Good	Average	Poor	Very poor
VLTs	4	6	2	0	0
NoVLTs	4	6	2	0	0

Q4′	Very much	Fairly	Not very	Not at all
VLTs	5	6	0	1

Scoring Key for Structural Knowledge Assessment

1 Lists include static lists and dynamic lists.

2 Static lists differ from dynamic lists in that static lists consist of a fixed number of items whereas dynamic lists can contain various number of items.

3 Static lists are represented by using one - dimensional arrays in computing.

4 There are three main operations on arrays: assignment, traversing, and searching.

5 The efficiency of searching is measured by the complexity.

6 Dynamic lists are represented by either trees or links.

7 There are six main operations on trees: building, maintenance, inserting, deleting, traversing, and searching.

8 The operation of inserting in trees is a component of building.

9 The operation of deleting in trees includes searching in trees.

10 Being balanced is the premise of the complexity discussion.

11 There are four main operations on links: inserting, deleting, traversing, and searching.

12 The operation of inserting links includes searching links.

13 In terms of the efficiency of searching, balanced trees are as good as arrays, but better than links.

The full score is 13x3=39. The total number of concepts is 13.

Scoring Key for Non - Structural Knowledge Assessment

1 Lists
    definition of lists
    properties of lists

2 Static lists
    definition of static lists
    properties of static lists

3 Dynamic lists
    definition of dynamic lists
    properties of dynamic lists

4 Arrays
    definition of arrays
    properties of arrays
    operations on arrays

assignment
traversing
searching
complexity of searching

5 Trees
definition of trees
properties of trees
operations on trees
building
maintenance
inserting
deleting
traversing
searching
complexity of searching

6 Links
definition of links
properties of links
operations on links
inserting
deleting
traversing
searching
complexity of searching

The full score is 31x3=93. The total number of topics is 31.

Appendix F Data and Statistics from Study Three

Table F.1.1 Data regarding learning outcomes from the VLTs group and its descriptive statistics.

Subjects	*Self-assessment*	*Delta*	*GEFT*	*Multiple 1 (%)*	*Multiple 2 (%)*	*Teach-back 1 (%)*	*Teach-back 2 (%)*
1	3	29	24	40	40	23.0769231	30.3571429
2	4	24	24	50	40	15.3846154	23.2142857
3	3	29	8	60	53.3333333	2.56410256	5.35714286
4	3	21	27	60	66.6666667	7.69230769	6.25
5	4	34	27	60	80	17.9487179	21.4285714
6	2	40	19	50	86.6666667	15.3846154	33.9285714
7	5	31	26	70	93.3333333	25.6410256	13.3928571
8	3	29	25	40	66.6666667	23.0769231	13.3928571
9	3	32	25	40	46.6666667	12.8205128	21.4285714
10	2	34	27	50	53.3333333	10.2564103	20.5357143
11	5	33	24	40	80	0	6.25
12	0	31	24	50	60	23.0769231	11.6071429
Mean	3.083333333	30.58333333	23.33333333	50.83333333	63.88888889	14.74358975	17.26190476
Median	3	31	24.5	50	63.33333335	15.3846154	16.9642857
Mode	3	29	24	40	40	23.0769231	6.25
Standard Deviation	1.378954369	4.888917585	5.297226261	9.962049199	18.08137237	8.406972466	9.420947494
Variance	1.901515152	23.90151515	28.06060606	99.24242424	326.936027	70.67718604	88.75425168
Kurtosis	1.263408517	1.071037937	7.221317914	-0.653808053	-1.202704595	-0.852863955	-0.842620584
Skewness	-0.675493058	-0.229180329	-2.575372835	0.470487829	0.202388265	-0.439892283	0.340710333
Range	5	19	19	30	53.3333333	25.6410256	28.57142854
Minimum	0	21	8	40	40	0	5.35714286
Maximum	5	40	27	70	93.3333333	25.6410256	33.9285714
Sum	37	367	280	610	766.6666667	176.923077	207.1428571

Table F.1.2 Data regarding learning outcomes from the NoVLTs group and its descriptive statistics.

Subjects	Self-assessment	Delta	GEFT	Multiple 1 (%)	Multiple 2 (%)	Teach-back 1 (%)	Teach-back 2 (%)
1	0	39	27	70	73.3333333	7.69230769	16.0714286
2	3	24	25	50	46.6666667	5.12820513	10.7142857
3	2	35	25	80	93.3333333	5.12820513	8.92857143
4	0	26	26	40	66.6666667	17.9487179	33.9285714
5	3	23	26	50	53.3333333	5.12820513	5.35714286
6	3	31	23	10	20	17.9487179	12.5
7	4	29	20	10	73.3333333	0	6.25
8	0	14	25	70	53.3333333	17.9487179	19.6428571
9	4	28	17	70	66.6666667	0	3.57142857
10	4	12	12	20	33.3333333	10.2564103	13.3928571
11	0	35	23	60	80	10.2564103	14.2857143
12	2	35	25	70	73.3333333	12.8205128	12.5
Mean	2.083333333	27.58333333	22.83333333	50	61.1111111	9.188034182	13.09523809
Median	2.5	28.5	25	55	66.6666667	8.974358995	12.5
Mode	0	35	25	70	73.3333333	5.12820513	12.5
Standard Deviation	1.676486224	8.382431122	4.427873147	24.86326242	20.66243032	6.510482955	8.025185494
Variance	2.810606061	70.26515152	19.60606061	618.1818182	426.9360268	42.38638831	64.40360221
Kurtosis	-1.680388838	-0.20873878	2.356083123	-0.98200692	0.096285165	-1.145857575	3.740949886
Skewness	-0.294866498	-0.681962864	-1.653848049	-0.681373835	-0.604173913	0.123382265	1.607674511
Range	4	27	15	70	73.3333333	17.9487179	30.35714283
Minimum	0	12	12	10	20	0	3.57142857
Maximum	4	39	27	80	93.3333333	17.9487179	33.9285714
Sum	25	331	274	600	733.3333332	110.2564102	157.1428571

Table F.2.1 The matrix of Pearson's *r* between seven data sets (Self-assessment, Delta, GEFT, Multiple 1, Multiple 2, Teach-back 1, Teach-back 2) for the VLTs group.

	Self-assessment	*Delta*	*GEFT*	*Multiple 1 (%)*	*Multiple 2 (%)*	*Teach-back 1 (%)*	*Teach-back 2 (%)*
Self-assessment	1						
Delta	-0.156199003	1					
GEFT	0.120305544	-0.102969237	1				
Multiple 1 (%)	0.193016989	-0.141548758	-0.126331466	1			
Multiple 2 (%)	0.301814286	0.451925853	0.118114418	0.451419809	1		
Teach-back 1 (%)	-0.19604592	0.060967562	0.397803089	0.062623438	0.069005578	1	
Teach-back 2 (%)	-0.158284051	0.450563598	0.162104891	-0.279638206	-0.159892376	0.433585172	1

Table F.2.2 The matrix of Pearson's *r* between seven data sets (Self-assessment, Delta, GEFT, Multiple 1, Multiple 2, Teach-back 1, Teach-back 2) for the NoVLTs group.

	Self-assessment	*Delta*	*GEFT*	*Multiple 1 (%)*	*Multiple 2 (%)*	*Teach-back 1 (%)*	*Teach-back 2 (%)*
Self-assessment	1						
Delta	-0.25606469	1					
GEFT	-0.647023668	0.458427494	1				
Multiple 1 (%)	-0.47981287	0.305335463	0.429395387	1			
Multiple 2 (%)	-0.370328499	0.580278515	0.320174125	0.625248142	1		
Teach-back 1 (%)	-0.567726215	-0.19256419	0.276272042	-0.100802065	-0.383141033	1	
Teach-back 2 (%)	-0.715917481	-0.122671251	0.318268803	-0.020339772	-0.023931116	0.76216155	1

t-Test: Two-Sample Assuming Equal Variances

	Teach-back 1 (%)	Teach-back 1 (%)
Mean	14.74358975	9.188034182
Variance	70.67718604	42.38638831
Observations	12	12
Pooled Variance	56.53178718	
Hypothesized Mean Difference	0	
df	22	
t	1.809909098	
P(T<=t) one-tail	0.04199656	
t Critical one-tail	1.717144187	
P(T<=t) two-tail	0.083993119	
t Critical two-tail	2.073875294	

Figure F.1.1 Microsoft Excel screen dump of t-test results, where the hypertext version is the independent variable while the first part of "teach-back" is the dependent variable.

t-Test: Two-Sample Assuming Equal Variances

	Teach-back 2 (%)	Teach-back 2 (%)
Mean	17.26190476	13.09523809
Variance	88.75425168	64.40360221
Observations	12	12
Pooled Variance	76.57892694	
Hypothesized Mean Difference	0	
df	22	
t	1.166298576	
P(T<=t) one-tail	0.127990938	
t Critical one-tail	1.717144187	
P(T<=t) two-tail	0.255981877	
t Critical two-tail	2.073875294	

Figure F.1.2 Microsoft Excel screen dump of t-test results, where the hypertext version is the independent variable while the second part of "teach-back" is the dependent variable.

Table F.3.1 Data regarding learning processes from the VLTs group and its descriptive statistics.

Subjects	*Time (min)*	*Cards browsed*	*Different cards browsed*	*Diagram mode*	*Index mode*	*Back mode*	*Recent mode*
1	30	47	22	41	0	5	0
2	33	51	22	42	3	5	0
3	45	38	22	37	0	0	0
4	53	71	22	59	0	11	0
5	50	48	22	36	0	3	8
6	32	50	22	45	0	4	0
7	44	29	22	19	8	0	1
8	59	63	22	29	32	0	1
9	45	39	22	36	1	1	0
10	54	45	22	33	5	1	5
11	24	35	22	29	3	0	2
12	47	45	22	32	11	1	0
Mean	43	46.75	22	36.5	5.25	2.583333333	1.416666667
Median	45	46	22	36	2	1	0
Mode	45	45	22	36	0	0	0
Standard Deviation	10.87950534	11.59251326	0	9.913260174	9.156468156	3.28794861	2.539088359
Variance	118.3636364	134.3863636	0	98.27272727	83.84090909	10.81060606	6.446969697
Kurtosis	-0.924659687	0.711474072	#DIV/0!	1.897856709	7.564234552	3.096014838	3.820631013
Skewness	-0.384267945	0.721533232	#DIV/0!	0.663479338	2.633052411	1.677315273	2.075839656
Range	35	42	0	40	32	11	8
Minimum	24	29	22	19	0	0	0
Maximum	59	71	22	59	32	11	8
Sum	516	561	264	438	63	31	17

Table F.3.2 Data regarding learning processes from the NoVLTs group and its descriptive statistics.

Subjects	*Time(min)*	*Cards browsed*	*Different cards browsed*	*Diagram mode*	*Index mode*	*Back mode*	*Recent mode*
1	47	49	22	42	2	4	0
2	25	34	22	26	0	5	2
3	49	65	22	51	5	3	5
4	33	39	22	37	0	1	0
5	42	59	22	42	4	12	0
6	51	58	22	48	0	9	0
7	30	41	22	39	1	0	0
8	38	44	22	28	3	10	2
9	39	37	22	35	1	0	0
10	73	156	22	72	46	37	0
11	59	50	22	32	0	0	17
12	49	48	22	37	8	1	1
Mean	44.58333333	56.66666667	22	40.75	5.833333333	6.833333333	2.25
Median	44.5	48.5	22	38	1.5	3.5	0
Mode	49	#N/A	22	42	0	0	0
Standard Deviation	13.18717237	32.67006785	0	12.27802916	12.88997731	10.38209414	4.88271534
Variance	173.9015152	1067.333333	0	150.75	166.1515152	107.7878788	23.84090909
Kurtosis	0.71326145	9.518394003	#DIV/0!	3.237507022	10.85856609	7.334119744	9.155294479
Skewness	0.654136274	2.967977036	#DIV/0!	1.516315645	3.245079313	2.553389532	2.950232966
Range	48	122	0	46	46	37	17
Minimum	25	34	22	26	0	0	0
Maximum	73	156	22	72	46	37	17
Sum	535	680	264	489	70	82	27

Appendix G An Example of Generating Fisheye Views

In this appendix, we will demonstrate a formal method of generating the fisheye-view structure diagram for the hypertext used in Study 2 and 3. The hypertext structure (see Chapter 5) has the following properties:

(1) although it takes the form of a network, it is indeed a hierarchy with cross-links (see Figure 5.10);

(2) the closeness of any two concepts is measured by the length of the shortest path between the two nodes which the two concepts are represented by;

(3) it has a starting node, namely *lists*, which represents the most general and important concept in the knowledge domain. The closer a node is to the starting node, the more general and important the concept that the node represents is.

The most important thing in generating fisheye views is to define an appropriate "Degree of Interest" (DOI) function which assigns to each point in the structure a number telling how interested the user is in seeing that point. Generally, a DOI function simply takes the form: $DOI(x|.=y) = API(x) - D(x,y)$, where $DOI(x|.=y)$ is the user's Degree of Interest in a point, x, given that the current point is y; $API(x)$ is the global *A Priori* Importance of x and $D(x,y)$ is the Distance between x and the current point y. It is obvious that the user's Degree of Interest increases with *a priori* importance and decreases with distance.

According to the properties of the sample hypertext structure described above, we can define such a DOI function for it simply as: $DOI(x|.=y) = (-d(x,SN)) - d(x,y)$, where SN stands for the Starting Node; $d(x,y)$ is the length of the shortest path between x and y in the network. Here, we use $-d(x,SN)$, the minus distance from x to the starting node, to represent the importance of the concept included in a node, x, because *further* from the starting node means *less* important.

Now that the DOI function has been worked out, we are going to illustrate how fisheye views are generated by using this function. Suppose the node *searching tree* (see Figure 5.10) is the current focus, we first calculate the function for the network at the supposed current focus. In order to make the calculation more explicit, we calculate the two components of the function separately as shown in Figure G.1 and G.2, and then put them together node by node to figure out the function value as shown in Figure G.3. In the illustration, each node consists of two parts: abbreviation of its thematic title and *A Priori* Importance/Distance/DOI. The bold node is the supposed current focus.

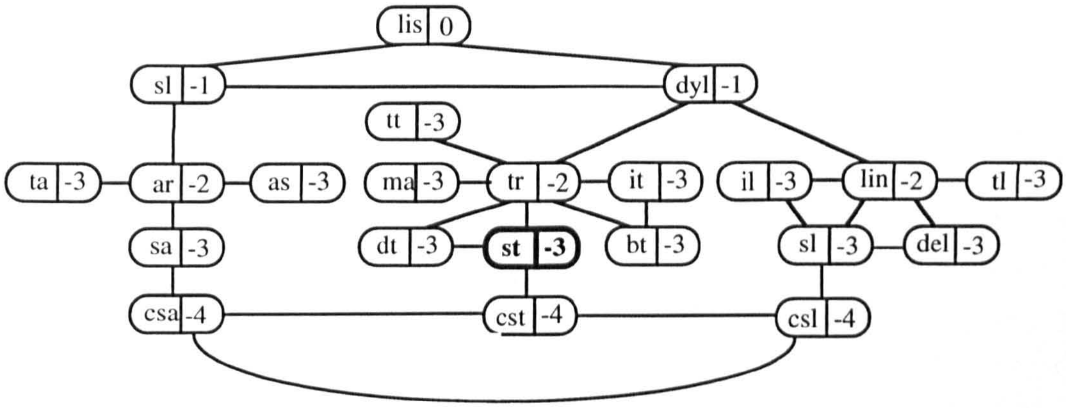


Figure G.1 Illustration of *A Priori* Importance. The larger the number is, the more important the node is.

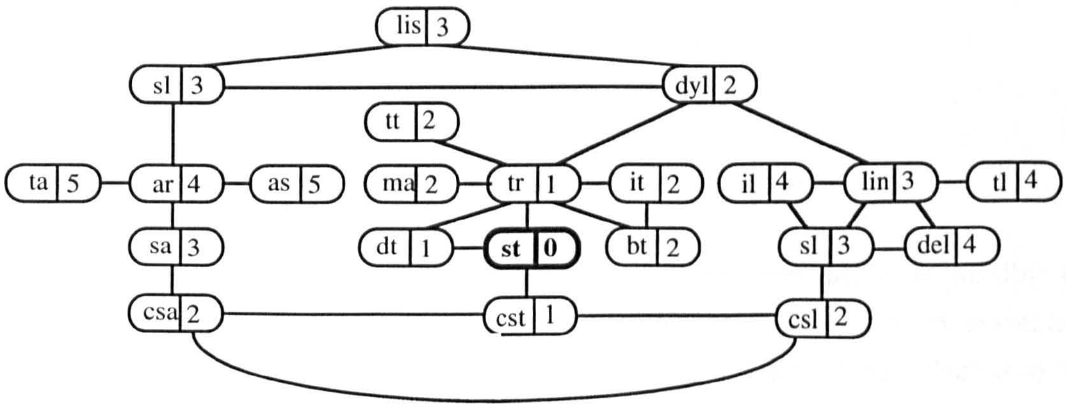


Figure G.2 Illustration of the distance from the current focus to each other node.

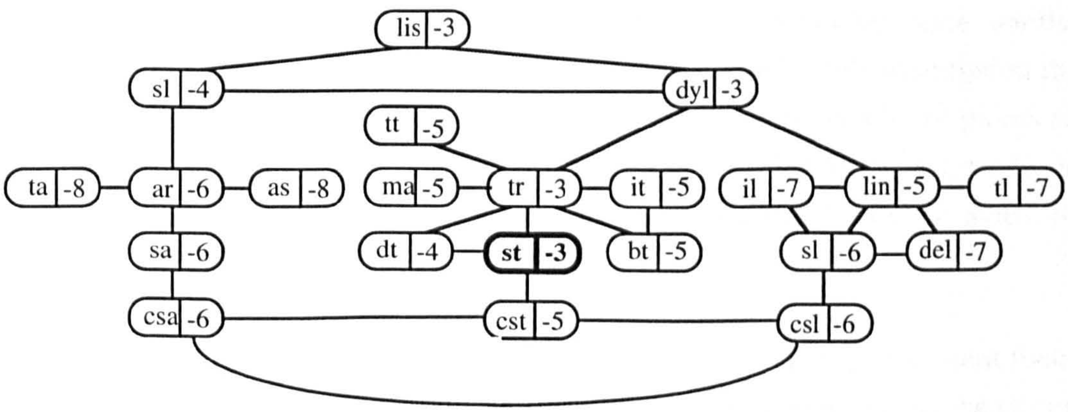


Figure G.3 Illustration of the DOI function values at the supposed current focus. The larger the number is, the more interesting the node is at the current focus.

The next step is to decide the size of fisheye views by choosing an appropriate threshold, k. Only those nodes with $DOI(x) \geq k$ will be displayed. Thus, one can obtain fisheye views of different sizes. For example, if we choose k=-3, the resulting view (shown in Figure G.4) is much smaller than the view (shown in Figure G.5) generated by letting k=-5.

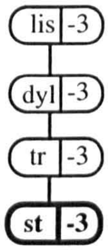


Figure G.4 A fisheye view generated by choosing *k*=-3.

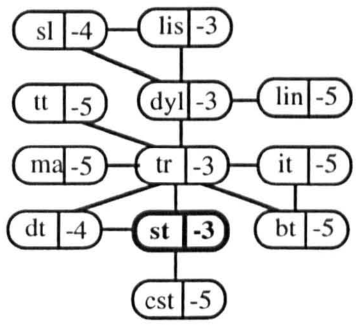


Figure G.5 A fisheye view generated by choosing *k*=-5.

The starting node, in fact, functions as a landmark in the network. It is possible to have multiple landmarks which usually occur in natural fisheye views, by assigning higher *A Priori* Importance scores to those prominent nodes that are selected to be landmarks. Landmarks are usually defined by the author of a hypertext system as part of the process of providing a usable structure for users. The author can choose landmarks according to different criteria. In addition to the starting node, another criterion might be the connectivity of nodes under the approximately assumption that those nodes that are referred to a lot and from which you can go to a lot of places are more important. For example, in our sample hypertext, nodes of *arrays*, *trees* and *links* have higher connectivities, and they can be regarded as candidate nodes for landmarks in addition to the starting node *lists*.

Every time when the user moves to another node, that is, changing his current focus, the value of the second element of the DOI function, i.e., the distance from the current focus to each other node, changes as well. Therefore, the DOI function has to be re-calculated. It is not difficult to work out that the time for calculating the DOI function is linearly proportional to the number of nodes in the hypertext, provided that the transitive closure of the links has been generated beforehand, which gives the length of the shortest path between each pair of nodes in the network. The main concern with the screen transformation speed results from the lower efficiency of methods of displaying structural diagrams. The time complexity of such an algorithm used in StackMaker (Hutchings, Carr, & Hall, 1992) is $O(n^2)$, where n is the number of nodes in the hypertext.